THE UNIVERSITY OF ALBERTA

COMPONENT CURVE ANALYSES
OF STUDENT PERFORMANCE
ON A COMPUTER-BASED SIMULATION GAME

BY

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A THESIS

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled, "Component Curve Analyses of Student Performance on a Computer-Based Simulation Game," submitted by J. Dale Burnett in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

The increased use of simulation games in education has prompted concern about the measurement of student performance within such a setting. Tansey (1970) has stated, "What is now urgently required is research... with finding evaluative systems that will enable the worth of the basic Technique to be measured".

The present study investigated the efficacy of one possible analytic system - Tucker's (1960, 1966) component curve analysis. The method was originally designed for analyzing a series of scores on a learning task for each of a number of individuals, and thus appears suitable for analyzing data from simulation games that provide some form of score at the end of each trial.

The sample consisted of 67 grade eight students that were randomly selected from one junior high school in Edmonton, Alberta. Each student interacted with a computer-based simulation game on the salmon fishing industry in British Columbia for a period of 10 cycles or 'years'. The scores for each student consisted of the value of the "cash on hand" variable at the end of each cycle. The students then received a computer-based version of the Matching Familiar Figures test, designed to provide a measure of impulsivity. The following week a set of 10 marker tests from the Kit of Reference Tests for Cognitive Factors (French, Ekstrom, and Price, 1967) were administered.

A component curve analysis of the raw performance data provided 4 component curves (i.e. learning curves) that were representative of 4 different patterns of performance. Factor scores for the students on the four curves were computed. Approximately one quarter of the students were

identified with a single curve. Orthogonal rotations in the person space increased this proportion to one half.

Additional component curve analyses were performed on the data after (a) the trial means were removed, (b) the person means were removed, and (c) both trial and person means were removed. There were no major differences among the results.

The measures obtained from the cognitive tests and the Matching Familiar Figures test were factor analyzed using Joreskogs (1967) maximum likelihood algorithm and then rotated using an equamax criterion. Five factors were identified: Associative (Rote) Memory, Verbal Compreshension, Number Facility, General Reasoning, and Impulsivity.

The relationship between the set of cognitive factor scores and the scores on the component curves was examined by means of canonical correlation and multiple linear regression. The main relationship was between the first component curve and the cognitive factors of Impulsivity, General Reasoning, and Number Facility. Additional relationships were observed between scores on component curve II and scores on General Reasoning and Impulsivity, and between curve IV and Number Facility. The three solutions obtained from the data matrices with trial and/or person means removed did not exhibit as strong a relationship with the cognitive factors. In simulation tasks of this type the use of the raw data matrix, which retains all of the available information, was recommended as the most satisfactory of the four alternatives for input to the component curve analysis.

A set of "random" performance data was generated by means of Monte Carlo techniques and then analyzed by means of Tucker's component curve analysis. Three component curves were required to account for the

data. Although this was unexpected, it may imply an additional application for Tucker's method since the number and shape of the component curves resulting from an analysis of random performance could be used as a method of classification for simulation games.

Referring to the component curve analysis of the actual student performance data, individual differences in performance were shown to be related to individual differences in cognitive abilities. The results of the study have indicated the potential value of Tucker's component curve analysis for describing student performance on a complex simulation game.

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CHAPTER I

INTRODUCTION

I. PURPOSE OF THE STUDY

The primary purpose of this study is to evaluate Tucker's component curve analysis as a method for describing student performance on a computer-based simulation game. Component curve analysis was designed to evaluate a series of scores on a learning task for each of a number of individuals. The method seems particularly appropriate for examining student performance on a simulation game that involves repetitive decision making with a "score" computed at the end of each set of decisions. Thus the study contains two main areas of interest: the context within which the data were obtained, computer-based simulation gaming, and the method of analyzing such data, component curve analysis.

The principal focal point is one of measurement - to further the understanding of the nature of the results provided by component curve analysis. The efficiency of the method, considered as a gain resulting from a reduction of data versus an accompanying loss of precision in reproducing the observed scores will be evaluated by means of the following criteria: the number of component curves compared to the number of trials, the shape of the component curves, the meaningfulness of various rotations, and the relationship of the factor scores for each component curve with a set of external measures (cognitive factors). Canonical correlation and multiple linear regression will be used to describe this latter relationship. The importance of evaluating a method for measuring student

performance on a computer-based simulation game is discussed in the next section, which provides a brief history of the development of this new instructional strategy within the context of the concurrent development in computer technology.

II. IMPORTANCE OF THE STUDY

The full impact of the new computer technology on our society is difficult to envision. In 1946 the first electronic computer, ENIAC, became operational. Today the variety of computers presently being used ranges from small desk-top stored program calculators to large time-sharing modular systems capable of handling the needs of thousands of users.

Education must be included in the list of professions that are likely to undergo major transformations in order to realize the potential provided. At present the impact on education may be felt in two areas:

1. Data processing applications in school administration.
2. Computational power needed for education research.

However as experience leads to refinements in these two areas, new areas will also develop. Two such new areas that appear to have a large potential are computer-assisted instruction (CAI) and real-time information retrieval systems.

Within the area of computer-assisted instruction there are at least three advantages provided by computer technology. First, complex calculations may be carried out in very short periods of time. This may be particularly relevant in subject areas such as mathematics, physics,

chemistry, and economics. Second, the use of graphics on automatic display devices will provide a pictorial representation of complex situations which in turn may lead to new problem-solving behaviors. Both of these advantages utilize the power of the computer to extend man's own capabilities. An example that utilizes both of these advantages is described by Levinthal (1966). He discusses a computer program that constructs mathematical models of large complex biological molecules and controls an equivalent pictorial display on an oscilloscope screen. The third advantage involves the possibility of utilizing the characteristics of present learning behavior to modify, and hopefully to improve, the characteristics of future learning behavior.

One type of instructional strategy that may be included under the heading of computer-assisted instruction is called simulation. The simulation of many situations that may or will occur in a person's real experience, or simulation of situations as a means or technique of teaching a particular concept has not been feasible until recently. However with the advent of computer technology such approaches will now become practical.

The advantages of computer-based simulation have been enumerated by a number of authors. Thus Bushnell (1967) feels that computer simulation possesses advantages over the actual observations of the natural events themselves.

> Time may be speeded up or slowed down. In comparison with traditional instruction through lectures and text-books, simulation brings a sense of immediacy to the learning task and may be considerably more realistic--thereby challenging the student to participate more actively. The student may learn to deal with systems far more complex than any he could learn to describe accurately in the same amount of time (p. 61).

Similarly Koch (1968) mentions the following advantages: enjoyment, holding the attention for a prolonged period, tendency for emotional involvement, avoidance of costly consequences of erroneous decisions, providing practice that could be too costly or unavailable otherwise, ability to add controlled feedback, progression from simple to complex, and elimination of negative or harmful experience. Also the subjects are able to see the consequences of their actions and to understand the interrelationships in the simulation. Carlson (p. 167-174) reviews the opinions of a number of researchers on the value of games as an instructional technique.

Whether or not such an approach succeeds in its intended goal may depend upon a number of variables. It may be that only students with a certain range of characteristics will benefit from such an approach. Analogously, it may be that there are characteristics of the simulation environment that will either enhance or reduce the possibility of success. Stolurow (1965), for example, feels that the essentials of programmed instruction fall under the following three headings--what is to be taught, who will be taught (i.e. characteristics of students), and how it will be taught (i.e. the teaching strategy). Furthermore, it is natural to hypothesize an interaction effect between these variables. Thus Bundy (1968) feels that ways must be found to design programs which will be able, in a sophisticated way, to analyze and act on student background, ability, and progress. This implies a systematic classification of individual difference variables and the study of their interaction with instructional materials and modes of presentation.

Further knowledge of these variables will enable a course planner to maximize the benefit achieved by including different modes of

instruction in a CAI environment. Within the restricted context of simulation, the instructor should be able to make use of the student's characteristics and performance in determining a suitable type of simulation model most appropriate for efficiently teaching a specified concept.

Implicit in the above statements is the assumption that powerful methods of analyzing student performance are presently available. Because of the complexity of the complete situation a multivariate approach would appear to merit special attention. One such development, referred to as component curve analysis, has been outlined by Tucker (1960, 1966). However Tucker's approach has only been applied to relatively simple learning situations - that of probability learning tasks. The present study examines the suitability of this approach for a much more complex learning situation, that of student performance during a computer-based simulation exercise.

III. SCOPE OF THE STUDY

Edwards and Cronbach (1952) distinguish two types of research - survey research and critical research. Thus survey research is undertaken when we are relatively ignorant of possible relationships among the variables and when we may even lack knowledge concerning the pertinent variables. With critical research theoretical considerations indicate the questions to be asked and even indicate the answers to be expected. Using Cronbach's definition as given above, the present study may be classified as survey research.

In order to meaningfully examine relationships between students and simulation models, it is important that the simulation model be

adequately described. At present there are no universal standards for describing a simulation model. However if comparisons are to be made among different studies using different simulation models, it is essential that descriptions of the models be provided. Therefore the first objective of this study is to define the dimensions for describing the simulation tasks used in the present investigation.

The second objective is to measure learning during the entire simulation process. This is much more desirable than using methods that only select and measure performance at one or two specified points, usually the last trial. Tucker's component curve analysis represents one such approach that utilizes information from the whole exercise and the efficacy of this method in studying learning under a complex repetitive task is evaluated.

The third objective of this study is to examine the relations between learning as measured by the component curves and outside measures of individual abilities and characteristics that have been shown in other studies to be related to learning tasks.

Therefore the results of this study may be summarized as follows:

1. to establish dimensions for use in describing simulation exercises
2. to evaluate Tucker's component curve analysis for measuring learning in a complex task
3. to relate performance in a simulation task as measured by component curves to a set of external measures.

CHAPTER II

SOME RELATED THEORY AND RESEARCH

I. COMPONENT CURVE ANALYSIS

Eckart-Young Theorem

Eckart and Young (1936) have developed a method for approximating, in a least squares sense, any matrix X by a matrix $\hat{X}$ of lower rank.

The Eckart-Young analysis of the data matrix X is given by the equation:

$$ {}_{n}X_{N} = {}_{n}V_{n}\ {}_{n}G_{n}\ {}_{n}W_{N} $$

where V is an orthogonal matrix ($V' = V^{-1}$)

W is an orthogonal matrix ($W' = W^{-1}$)

G contains the eigenvalues, λ_i in the diagonal elements of the matrix and zeros elsewhere.

Tucker's component curve analysis uses a variant of this procedure to analyze data from a learning task. When the scores in the X matrix represent learning data, then the V matrix reflects a set of learning curves and the W matrix describes the individual's behavior relative to these curves.

Tucker's Component Curve Analysis

The essential feature of component curve analysis resides in the type of data which forms the matrix X that undergoes the analysis. Tucker's method consists of applying the Eckart-Young theorem to a particular type of data matrix. The raw data must consist of a series of

scores on some task for each of a number of individuals - essentially a repeated measures design applied to some learning situation.

Tucker (1960, 1966) has shown the suitableness of the component curve analysis for studying the learning curves for a probability learning task. Tucker used the following model:

$$X_{ji} = b_{j1}Y_{1i} + b_{j2}Y_{2i} + \ldots$$

where X_{ji} is the score on the trial j (j = 1, 2, . . . m) for individual i (i = 1, 2, . . ., n), b_{j1}, b_{j2}, etc. are coefficients dependent on the trials, and Y_{1i}, Y_{2i}, etc. are individual parameters. There are m trials and n individuals. This model, which is identical with the basic factor analytic model, may be interpreted as follows, "the series of scores of an individual is a weighted sum of reference learning curves, the weights being the individual factor scores and the series of b's for each factor forming a reference learning curve (p. 483)."

Using the Eckart-Young theorem, an approximate matrix $\hat{X}_k$ (of rank k) is formed by using the first k left principal vectors, (cols.) in V, principal roots in G, and right principal vectors (rows) of W to form the matrices V_k, G_k, W_k such that

$$ {}_n\hat{X}_{k_N} = {}_nV_{k_k} \; {}_kG_{k_k} \; {}_kW_{k_N} \tag{1}$$

Tucker defines the matrices,

B_k^* and Y_k^* as follows:

$$B_k^* = N^{-1/2} \; V_k G_k \tag{2}$$

$$Y_k^* = N^{1/2} \; W_k \tag{3}$$

where $N^{1/2}$ is a scaling factor to ensure that the mean square of each row of Y_k^* is unity.

Thus $$\hat{X}_k = B_k^* \; Y_k^* \tag{4}$$

Recall that $X = VGW$

and therefore $XX' = VGWW'G'V'$

$$= VGG'V'$$

$$= VG^2V'$$

This equation can be solved using the familiar Hotelling principal axes algorithm. Jacobi and Householder have developed two alternate methods for solving this equation. The number of principal roots and vectors may be determined by inspection and B_k^* is easily computed using equation (2). It remains to show how the values for Y_k^* are determined.

Since $B_k^* Y_k^* = \hat{X}_k$,

pre-multiplying both sides by $B_k^{*'}$ yields

$$B_k^{*'} B_k^* Y_k^* = B_k^{*'} \hat{X}_k \ . \qquad (5)$$

Also $B_k^* = N^{-1/2} V_k G_k$ (see equation (2)).

Therefore

$$B_k^{*'} = N^{-1/2} G_k' V_k' = N^{-1/2} G_k V_k' \ .$$

Substitution into equation (5) gives

$$(N^{-1/2} G_k V_k')(N^{-1/2} V_k G_k) Y_k^* = B_k^{*'} \hat{X}_k$$

$$N^{-1} G_k V_k' V_k G_k Y_k^* = B_k^{*'} \hat{X}_k$$

$$N^{-1} G_k^2 Y_k^* = B_k^{*'} \hat{X}_k$$

$$Y_k^* = N G_k^{-2} B_k^{*'} \hat{X}_k$$

Since the first k eigenvalues and eigenvectors of X are identical to those of $\hat{X}_k$, the known data matrix X is substituted for $\hat{X}_k$, giving us the solution

$$Y_k^* = N G_k^{-2} B_k^{*'} X \qquad (6)$$

where all terms on the right hand side of (6) are known.

The Eckart-Young procedure shows that if $\hat{X}_k = B_k^* Y_k^*$ then $\Sigma\Sigma(X_{ji} - \hat{X}_{ji})^2$ is a minimum for the selected k, i.e., sums of squares of errors are minimized, where B_k^* may be interpreted as the factor loading matrix, Y_k^* may be interpreted as the factor score matrix. Summarizing, Tucker used the formulation

$$\begin{aligned} \hat{X}_k &= V_k G_k W_k \\ &= (N^{-1/2} V_k G_k)(N^{1/2} W_k) \\ &= B_k^* Y_k^* \ . \end{aligned}$$

Within the context of component curve analysis there are a number of unresolved issues. Thus there are a number of decisions, each containing an element of subjectivity, that must be made by the experimenter who decides to use a component curve approach. These are discussed in the following four sections.

Issue on Choice of Matrix

Ross (1964) has discussed the difference in factor structure resulting from the factorization of correlations, covariances or cross-products and recommends the use of cross products for factoring learning data since this method retains information on both means and variances.

Tucker (1956) noted that the removal of trial means from the data matrix is appropriate when the scale of measurement is consistent for each variable over the population of people, that the removal of person means is appropriate when the scale of measurement is consistent for each person over the population of observations, and concluded that the use of a double centered score matrix may be appropriate when both

conditions are satisfied.

The type of simulation game used in this study consists of presenting the student with a set of variables, some of which the student is allowed to modify directly and some of which are modified as a result of changes made to other variables. From a general point of view the task and the setting remains the same for each trial, but the actual values of the variables will change from trial to trial depending upon the decisions made by the student.

Within the context of analyzing student performance data on such a computer-based simulation game, Ross' (1964) suggestion of using the cross-product matrix seems the most appropriate since this method retains all of the available information. However, to the extent that one can consider the trials to be exactly the same, it is desirable to also investigate the nature of the solution derived from the variance-covariance matrix (i.e. trial means removed); to the extent that one can consider each subject having a propensity towards one type of approach to the simulation game, the raw data matrix with the person means removed should be analyzed; and to the extent that both conditions are assumed to be valid, the double centered score matrix should be used.

The present study will investigate the results from analyzing the four matrices mentioned above, namely the raw data matrix, the data matrix with trial means removed (variance-covariance matrix), the data matrix with person means removed, and the double centered data matrix (both trial and person means removed).

Issue on Number of Components

Tucker (1960, 1966) used two different criteria for determining the number of components that should be used to adequately describe the

data. The first of these criteria was a mean square ratio.

Let ${}_nX_N$ represent the data matrix for n trials and N individuals and let λ_p represent the p th eigenvalue resulting from an Eckart-Young decomposition of X. Then Tucker points out that the following equations involving sums of squares are valid.

$$\sum_{j=1}^{n}\sum_{i=1}^{N} x_{ji}^2 = \sum_{p=1}^{\min(n,N)} \lambda_p^2$$

$$\sum_{j=1}^{n}\sum_{i=1}^{N} \hat{x}_{ji}^2 = \sum_{p=1}^{k} \lambda_p^2$$

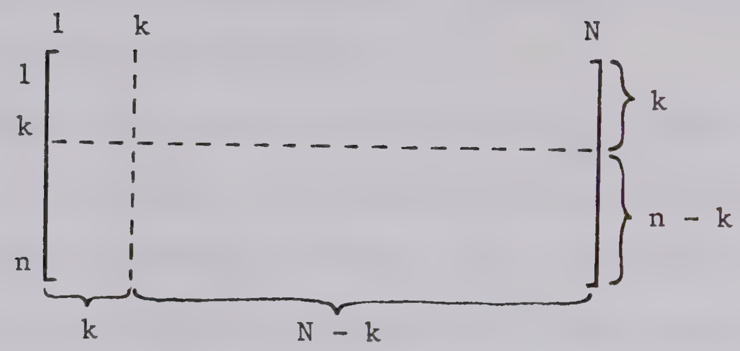
$$\sum_{j=1}^{n}\sum_{i=1}^{N} e_{ji}^2 = \sum_{p=k+1}^{\min(n,N)} \lambda_p^2$$

$$\sum_{j=1}^{n}\sum_{i=1}^{N} x_{ji}^2 = \sum_{j=1}^{n}\sum_{i=1}^{N} \hat{x}_{ji}^2 + \sum_{j=1}^{n}\sum_{i=1}^{N} e_{ji}^2$$

In order to determine the importance of the k th factor, Tucker considers the following ratio of sums of squares where an adjustment must be made for degress of freedom in order to have a mean square ratio:

$$\frac{\lambda_k^2}{\displaystyle\sum_{p=k+1}^{\min(n,N)} \lambda_p^2}$$

Since Tucker does not provide a derivation for this formula, when he suggests that it is approximately distributed as F, the following explanation is given. The degrees of freedom for the data matrix is equal to the number of independent observations, nN. Let the matrix be partitioned as follows:



Thus the total degrees of freedom may be partitioned into four components,

$$nN = k^2 + k\,(N-k) + k\,(n-k) + (N-k)\,(n-k).$$

Tucker then sets the degrees of freedom for the errors of approximation, $(DF)_k$, equal to $(N-k)\,(n-k)$,

and the degrees of freedom for the first k factors, $(df)_{\Sigma k}$, equal to the remaining degrees of freedom,

$$(df)_{\Sigma k} = k^2 + k(N-k) + k(n-k)$$

To determine the degrees of freedom for just the k th factor, $(df)_k$, the following equation must be solved:

$$\begin{aligned}(df)_k &= (df)_{\Sigma k} - (df)_{\Sigma(k-1)} \\ &= k^2 + k(N-k) + k(n-k) - \left[(k-1)^2 + (k-1)(N-k+1) + (k-1)(n-k+1)\right] \\ &= n + N + 1 - 2k\end{aligned}$$

Therefore Tucker ends up with the following mean square ratio for the k th factor:

$$(MSR)_k = \frac{\lambda_k^2\,(N-k)(n-k)}{\Sigma\,\lambda_k^2\,(n+N+1-2k)} = \frac{\lambda_k^2\,(DF)_k}{\Sigma\,\lambda_k^2\,(df)_k}.$$

Tucker pointed out that the distribution of this ratio is unknown, but that the F distribution provides an adequate approximation for large sample sizes. Thus at present this approach does not provide a

decisive decision criteria for the number of components to be retained but it does provide an approximate test.

Tucker's second criteria for determining the number of components was based on the concept of external validity. If a learning component curve is to be considered meaningful (ie. it represents a consistent learning behavior instead of a fluctuating random behavior) it should form a smooth curve. Therefore a subjective, visual review of the plotted curves provides the second criteria. Tucker has provided a quantitative measure, d^2, of the smoothness of a curve, where d^2 is equal to the sum of squares of the differences between consecutive coefficients of the curve. Unfortunately at present there is no statistical test associated with this measure.

Weitzman (1963) has provided a third approach to the problem of the number of factors to be retained.

> Since the first factor component curve accounts for the most variance possible and thus approximates the over-all mean curve and since all the factor component curves are mutually orthogonal, the remaining factor component curves should fluctuate about the zero line. Any significant trends in this fluctuation will be indicated by the runs test, if the runs consist of pluses and minuses representing fluctuations of the factor component curves above or below the zero line.

When all three criteria give the same result reasonable confidence should be placed on the decision. It is expected that the three criteria will be in close agreement for the majority of situations.

Issue on Shape of Component Curves

The interpretation given to the shape of the components is also subjective. Tucker considered data from a probability learning task where the raw scores consisted of the number of correct responses for each subject over twenty-one consecutive sets of twenty presentations.

He characterized a curve that was well above zero at all times as early learning, a curve that started near zero and continued to rise as middle learning, and a curve that started near zero and follwed the base line for about six trials before starting to rise as late learning. Weitzmann appears content to note the existence of more than one curve and does not provide an interpretation of the individual curves. It is also possible to interpret large deviations from zero as accounting for a larger proportion of the variance at that particular trial.

A review of two studies (Tucker, 1960; Burnett, 1971) indicates that Tucker's component curve analysis may produce component curves with approximately the same shape. Thus each successive component curve appears to have a wavelength approximately one-half that of the preceeding component curve. This study will provide further information on this topic by comparing the shape of the component curves resulting from an analysis of student performance data on a simulation game with the component curves resulting from an analysis of data that simulates "random performance".

The issue on the shape of the component curves is further complicated by the problem of rotation, since the shape of the curves will vary with the rotation of the axes.

<u>Issue on Rotation of Axes</u>

There are two principal reasons for rotating the axes:

(1) to enhance the meaningfulness of the learning curves, and

(2) to provide maximum separation among the subjects.

At present there are no firm guidelines as to what constitutes a meaningful

or desirable rotation. The relationship between rotation and the above considerations will be discussed separately. First, consider the concept of meaningfulness of the component curves. As was mentioned previously, the component curves should be relatively smooth - a ragged sawtooth curve does not fit our conception of a learning curve. Therefore any rotation (i.e. transformation) that noticeably reduces the smoothness of the component curves would be considered undesirable. Also the general shape of the curves should be interpretable within the context of the learning task, in this case a simulation game. Both of these criteria require a subjective evaluation of the results from a particular rotation. However it is at least equally important that the theoretical basis for a particular rotation be relevent to the given situation. For example, a rotation may tend to distribute the variance over the derived component curves. The issue thus becomes one of deciding whether it is better to emphasize the maximum possible variability at each step or whether one should identify the different component curves and then attempt to equalize their contribution to the variance accounted for. Another feature of rotation deserves mention. A linear transformation, such as a rotation, applied to a set of component curves does not affect the canonical correlation with another set of external measures. Therefore nothing is either gained or lost with respect to the overall relation between the two sets of data when a rotation is performed.

It follows that a rotation designed to increase the separability among the subjects will not have a detrimental effect with respect to the relation with a set of external measures, considered as a set. One natural approach to this objective is to apply a simple structure criterion to

the set of scores on the component curves (i.e. in the person space). This possibility will be intestigated in this study.

In order to clarify the objective of the present study with respect to the issue of rotation, it is convenient to classify rotations into four groups depending upon the criteria for rotation: simple structure in the trial space, simple structure in the person space (which will be investigated in this study), rotation to a specified target, and rotation to maximize or minimize a particular criterion. The restriction to an orthogonal rotation appears desirable since this ensures the independence of components. It is possible that oblique rotations will come into use after more development with the procedures has occurred.

Tucker considered the criteria of simple structure in the trial space but rejected the idea for theoretical reasons - he was unable to justify why one would want many zeros in the component curves over trials. This possibility was also investigated by Burnett (1971) who applied quartimax, varimax, and equamax rotations to the trial space but no noticeable improvement in simple structure was noted. Thus the concept of simple structure in the trial space does not appear to hold much promise, from either a theoretical or practical point of view.

Tucker also looked for simple structure in the person space to see if individuals followed different component curves but the results were negative. He finally used a graphical procedure for rotation such that all component curves had non-negative entries, non-negative slopes, and that they all reached an asymptote. Burnett (1971) applied quartimax, varimax, and equamax criteria in the person space and achieved more encouraging results - approximately eighty percent of the students could be identified with a single component. Therefore these rotations will be

considered in the present study to provide further information on these methods of rotation.

The methods of rotation to a specified target and rotation to maximize or minimize a particular criterion require a depth of understanding about both the nature of performance data on a simulation game and the characteristics of component curve analysis that is not available at the present time. Thus an investigation of these methods appears premature until further research is carried out in both simulation gaming and in component curve analysis.

II. SIMULATION TEACHING TECHNIQUES

Classification of Simulation Games

No universal taxonomic system exists for classifying simulation models. Moss (1958) has suggested a five point scale based on the degree of abstraction. Naylor (p. 16) uses an arbitrary four category scheme. Samuelson (p. 315) has proposed a sixfold classification of dynamic systems. The type of model to be considered in this study falls into his sixth group, dynamic stochastic and historical.

Beck and Monroe (1969) emphasize six dimensions that may be used to describe simulation models:

1. Reality - the degree of fidelity to a real life situation
2. Complexity - includes consequences for the learner, response choices, social factors, and constraints on time or length
3. Curriculum Content - determined by the learning objectives,

characteristics of the learner, and bias of the designer

4. Model design - a synthesis of the mode in which the model operates (eg: computer-based) and the degree of mathematics used

5. Replicability - allows for identical trials

6. Evaluation - related to teaching-testing cycles

Any description of a simulation exercise should include sufficient information to allow a clear judgement of the model's characteristics as they relate to these six dimensions.

The Issue of Realism Versus Abstraction

Verba (1964) defines simulation as a dynamic model of a system. "Other models...may attempt to represent a system through verbal means, mathematical means, or pictorial means. But the simulation model differs in that it is an operating model". The concept of an operating model is recognized by Raser (p. 10), Dawson (p. 3), and Naylor (p. 3).

Boguslaw (1965) distinguishes between replica and symbolic models: replica models are material and look like the real thing whereas symbolic models use ideas, concepts, and abstract symbols to represent objects. Raser (p. 11) points out that a simulation abstracts, simplifies, and aggregates, in order to introduce into the model more clarity than exists in the referent system. Which components and relationships are included depends upon the purpose and goal of the experience.

Thus many training programs use simulations that involve a high degree of realism. However, other simulated situations may use a highly

simplified model in order to focus attention on specific variables. This is elaborated upon in the following three sections which discuss the range of simulation usage within an instructional frame of reference.

Training Programs

Perhaps the most familiar application of simulation is in the area of training. The importance of this technique was brought into the public spotlight recently as information was released on the training program for man's first journey to the surface of the moon. Simulation is also widely used for training airplane pilots and for automobile driving instruction. In all of these instances the simulator is a relatively accurate reproduction of a complex man-machine-environmental system.

Jacobson (1966) mentions the need for a simulation that provides internal and external visual cues of a high degree of realism for the training of astronauts in the Gemini program. Chapman's (1959) description of the RAND Air Defense Simulation experiments and Cohen's (1960) description of the Carnegie Tech Management game both emphasize the external realism of the simulation situation. An excellent discussion of the objectives and results of using the Carnegie game is presented by Dill and Doppelt (1965).

Tansey (1970) reviewed a number of simulation techniques used in the training of teachers. Developments at the Oregon State System of Higher Education, Indiana University, Michigan State University, University of Tennessee and the Berkshire College of Education in England were all discussed. The general theme of all the projects centered on the need to integrate the theory and practice of education more closely in the training of student teachers. The projects did not rely on a high

degree of realism with a classroom situation - the Oregon system presented a number of classroom incidents via a film projector and the student was expected to respond in an appropriate manner, in Berkshire the initial situation was presented via a printed report and the student teacher was required to give a written reply describing his action.

Use of Simulation Games as an Instructional Technique

Practical and economic difficulties impose restrictions on the types of simulation that are suitable for use in a school system. At present the majority of such techniques consist either of situations that primarily involve the interaction of students, such as social simulation (SIMSOC, GHETTO, COMMUNITY DISASTER, and INTER-NATION) or situations that require very simple, if any, computations (CARIBOU HUNTING, GAME OF RAILROADING, WATERLOO, and MARKET GAME).

Zuckerman and Horn (1970) have prepared a bibliography of 404 games which includes brief descriptions for the games mentioned above. The authors estimate that, "the 404 games listed represent only a portion, perhaps as little as a third, of the games presently in use (p. 1)."

Because of the "game" feature, many of these exercises are being developed by private companies for sale to the general public. The resulting proliferation of such games has definitely outstripped accompanying research. Boocock and Coleman (1966) and Boocock (1966) have discussed the effectiveness of three non-computer based simulation games from both a motivation and learning point of view. Cherryholmes (1966) suggested that the case for learning and attitude change resulting from simulation games may not be as strong as has been claimed, but this is

qualified by the statement, "One serious weakness in much evaluatory research has to do with the criterion problem - i.e., specifying what a given set of materials is supposed to teach and then devising tests to measure this accurately". This receives further elaboration in a later section of this study, Evaluation of Simulation Games.

The High School Geography Project (Watson, 1969; Helburn, 1967; 1968; Kurfman 1967) represents one attempt to integrate simulation gaming directly into a course, rather than to just use a simulation game as "enrichment" material. It seems fair to conclude that the use of simulation games is experiencing a popular rise in prominence - but that research into its effectiveness has lagged behind. The emergence of computer technology should provide further impetus to both aspects, as discussed in the following two sections.

Advent of Computer Based Simulation Games

With the advent of computer technology a new level of simulation exercise has become possible. Models that involve complex calculations, models that contain complex interaction among variables, and models that provide individualized feedback to the student are now possible. These models would be classified by Boguslaw (1965) as symbolic, however the form of the output on the printer, cathode ray tube, and slide projector are all intended to add realism to the exercise. A new development which may have far reaching possibilities is the generation of holograms (three dimensional pictures). Hendren (1968) is interested in the computer generation of synthetic holograms in order that designs may be viewed in three dimensions, from different viewpoints, and in motion.

Wing (1967) has developed three economic games for sixth grade

students: the Sumerian Game, the Sierra Leone Game, and the Free Enterprise Game. The sophistication of these games is only made possible by the use of a computer. Lagowski (1968) has helped develop a chemistry course that simulates the laboratory experiments. Naylor (p. 10) mentions a number of sophisticated simulation models: the shoe, leather, and hide industry, the West Coast lumber industry, the United States economy in recession, and a behavioral theory of the firm. However at present these latter models are being used to gain a further understanding of the processes involved and are not yet designed for use as an instructional technique.

Lekan (1969, 1970) has compiled two bibliographies for computer assisted instruction materials. In 1969 there were 36 programs that were classified as using simulation, whereas in 1970 the number had increased to 84. These programs are used in biology, chemistry, computer programming, economics, education, medicine, political science, management and mathematics courses.

Although a number of programs are presently being developed, the report by Wing (1967) represents one of the few published studies that has evaluated the use of simulation models as an instructional technique. The main purpose of his study was to evaluate the effectiveness of simulation in teaching economic understanding. Wing enumerates fourteen conclusions arising from the study, with the general trend supporting the use of simulation.

Evaluation of Simulation Games

The objective evaluation of simulation games and the interrelated issue of evaluation of subjects' performance on a simulation

exercise is still at an embryonic stage. Tansey (1970) describes the present situation as follows:

> What is now urgently required is research that is not concerned primarily with the production of materials but with finding evaluative systems that will enable the worth of the basic technique to be measured. ...The setting up of simulation exercises is a laborious and often expensive process, and we urgently need accurate information in order that we can feel a measure of certainty that it is worthwhile.

Attempts at evaluation may be categorized into two main approaches: those that rely on some form of post-simulation test and those that obtain a measure directly from the subject's performance on the simulation exercise.

Examples of the post-simulation test approach include those of Burke and Sage (1970), and Clarke (1970) who used an instrument based on Osgood's Semantic Differential to obtain scales that measured concepts related to the simulation exercise. Burke and Sage observed the hypothesized direction of attitude change as a result of the simulation exercise, for 9 of the 10 concept scales. Clarke concluded that students who participated in the simulation exercise displayed a consistently more positive response to the relevant concepts than did a control group. Stahl (1970) used a similar procedure to examine the degree to which an individual is effectively involved in a number of simulation problems presented via different media. Using the moods adjective checklist (MACL) he obtained scores on factors such as anxiety, elation, fatigue, and nonchalance, both before and after the simulation exercise. A total of twelve mood factors were considered. Eight factors displayed a significant change after a video tape presentation, two factors had a significant change after an audio presentation, and three such factors were noted after a

written presentation. The traditional post-test method for measuring the learning of facts and principles was used in the six studies reviewed by Cherryholmes (1966), and was also used in studies reported by Boocock (1966), Wing (1967), and Anderson (1970). Anderson concluded, "... learning factual information about installment credit through a simulation learning game is as effective as reading, discussing, and reporting about the use of installment credit in a conventional classroom approach ...". In general, few significant differences have been observed between experimental groups (simulation gaming) and control groups (classroom approach).

Kersh (1963) has provided one study where the subject's score was a direct function of his performance in the simulation situation. He applied rating standards to the alternatives for each classroom problem in a teacher training situation and summed the scores over a sequence of twenty problems to obtain a composite rating for each trainee.

Final results on any of the economic games would represent another simple measure of student performance. However other methods which take explicit account of most, if not all, of the available information on a student's performance would seem to merit further consideration. Component curve analysis represents a step in this direction.

III. EXTERNAL MEASURES OF SUBJECTS' CHARACTERISTICS

The French Kit of Cognitive Factors

Both Duncanson (1966) and Lemke, Klausmeier, and Harris (1967) have shown relationships between learning tasks and the factors measured

by the Kit of Reference Tests for Cognitive Factors collected by French, Ekstrom, and Price (1967). Reed (1966) explored the relationship between a measure of conceptual complexity, the Paragraph Completion Test and the cognitive factors measured using the French kit and concluded that, "the general reasoning factor involves an ability to structure problems and to deal with complexity, where complexity is defined by the number of elements and relations in a problem". Wampler (1966) has used several of the tests from the French kit to successfully predict performance in college mathematics.

The Kit of Reference Tests for Cognitive Factors provides a set of marker tests for twenty-four cognitive factors. Five of these factors appeared to have particular relevance for the present study. These factors are described by French _et al_ as follows:

Induction: associated abilities involved in the finding of general concepts that will fit sets of data, the forming and trying out of hypotheses.

Marker tests: 1-1, Letter Sets Test (grades 8-16)(14 minutes)
1-3, Figure Classification (grades 8-16) (16 minutes)

Associative (Rote) Memory: the ability to remember bits of unrelated material. Tests requiring _recall_ of items in isolation do not have a loading on this factor. It is possible, although there has been no clear demonstration yet, that this factor represents the ability to form and remember new _associations_ quickly.

Marker tests: Ma-2, Object-Number (grades 6-16) (10 minutes)
Ma-3, First and Last Names Test (grades 6-16) (10 minutes)

Number Facility: the ability to manipulate numbers in arithmetical operations rapidly. There is a little evidence that certain kinds of manipulation of symbols other than numbers can load this factor.

Marker tests: N-1, Addition (grades 6-16) (4 minutes)

N-3, Subtraction and Multiplication (grades 6-16) (4 minutes)

General Reasoning: The ability to solve a broad range of reasoning problems including those of a mathematical nature.

Marker test: R-1, Mathematics Aptitude (grades 6-12) (10 minutes)

R-4, Necessary Arithmetic Operations (grades 6-16) (10 minutes)

Verbal Comprehension: the ability to understand the English Language.

Marker test: V-1, Vocabulary (grades 7-12) (8 minutes)

V-2, Vocabulary (grades 7-12) (8 minutes)

A copy of the test direction page, which includes examples, for each of the above tests may be found in Appendix A.

A review of the descriptions provided by French indicated that a positive relationship should exist between student performance on a simulation game and the factors of induction, associative (rote) memory, number facility, and general reasoning. It was possible to postulate that students may not attach the same meaning to either the instructions or the variables used in the model, therefore marker tests were included to measure the factor of verbal comprehension.

Matching Familiar Figures Test

Another relevant dimension for the present study was that of impulsivity. The temporal stability and inter-task generality of a tendency toward fast or slow decision times to problems with high response uncertainty has been demonstrated (Kagan, 1966b). This dimension was measured by means of Kagan's Matching Familiar Figures (MFF) test, modified for a computer-based presentation (see Apprendix C).

In this test the subject is shown a picture of a familiar object, called the standard, and six similar stimuli, only one of which is identical to the standard (Figure 2). The subject is asked to select the one stimulus that is identical to the standard. Errors and response times are recorded for each of the twelve test items.

Kagan has used two different measures of impulsivity. In one study (1966b), "Impulsive children were above the median on total errors and below the median on average response latency (for all 12 items) for their sex. Reflective children were below the median on errors and above the median on response latency." However in another study (1966a) Kagan used both the above method and another procedure which only considered the response latency time. He concluded, "We have never found qualitatively different results when we used response time alone or combined response time with errors as the index of the reflection-impulsivity dimension." Thus the response latency time could prove useful for providing a single direct measure of impulsivity during an actual simulation exercise, since in this situation a subject's response usually cannot be scored as correct or incorrect.

CHAPTER III

PROCEDURE

I. DESCRIPTION OF SAMPLE

The subjects for this study were all sampled from the population of Grade Eight students at Wellington Junior High School in Edmonton, Alberta. The students at Wellington Junior High School are drawn from four widely differing socio-economic districts and represent a general cross-section of the low to high-middle income groups, and in this sense may be considered representative of the majority of students in an urban environment.

There were two principle reasons for selecting grade eight students. First, the restriction of sampling from one grade level minimizes age differences and thereby provides a form of control over this source of variation. This helps to minimize the confounding effect of age on the cognitive factors and also helps to minimize the effect of an age factor related to maturity and sophistication which could have some relation to operating an abstract exercise such as a simulation game.

Second, since the simulation game used in this study models the salmon fishing industry of British Columbia, it was desirable to have students whose normal curriculum would include an examination of the fishing industry. This is currently considered a part of the grade seven Social Studies curriculum in Alberta. Grade eight students were selected instead of grade seven students to avoid the possibility that some students may have studied fishing just prior to participating in the study. Thus grade

eight students satisfy the following criteria:

1. Age is similar to that of students who normally discuss the fishing industry in their curriculum.
2. Prior knowledge of the fishing industry is approximately equal - since almost a year had elapsed since they had last studied the fishing industry.

The actual students used in the study were sampled according to the following procedure. First, a complete list of all grade eight students registered in Wellington Junior High School was obtained. The complete list totalled 274 students from 9 different classrooms. Each student was then assigned a unique number from the range 1 to 274. The APL 360 System (Falkoff and Iverson, 1968), using the function 75 ? 274, was used to obtain a vector of 75 random numbers, without replacement, from the range 1 to 274. The 75 students whose numbers matched those that were obtained from the random number generator were used in the study.

Each of the selected students was given a letter asking for their parents' permission to participate in the study. A copy of the form letter is included in Appendix E. All of the parents gave their consent to having their children take part in the study.

Although 75 subjects were selected by the random procedure, only 67 subjects were included in the analysis. Eight students were excluded from the final analysis for the following reasons: 1 student moved, 2 students had incomplete data for the simulation game, 1 student had incomplete data from the set of marker tests for cognitive factors, and 4 students were absent when the marker tests were given. A further explanation regarding the issue of incomplete data is necessary. The incomplete

data for the simulation game for two students was caused by an error in the computer program for the simulation game. This error was subsequently corrected and no further problems were encountered among the other students. Incomplete data on the marker tests for one subject was caused by a misunderstanding on the directions for one of the tests - as a result the subject failed to complete one of the tests.

The 67 students composing the sample for this study consisted of 28 boys and 39 girls. The random sampling procedure selected students from all 9 classrooms. Their age varied from 12 years, 1 month to 14 years, 10 months - representing a range of 2 years, 9 months. The mean age was 13 years, 6 months and the standard deviation was 6.26 months.

The father's occupation for each of the students in the study was obtained from the school records. Forty-four of the sixty-seven records were sufficiently precise to permit the assignment of a value from Blishen's (1967) Socio-Economic Index. Occupational information for an additional fifteen subjects was obtained from Henderson's Edmonton, Alberta City Directory (1970). Thus a total of 59 of the 67 subjects (88%) were used to calculate a Socio-Economic Index for the Wellington sample. This scale is based on the 1961 Canadian census data and takes into account information on income, education, and prestige - as measured by the Pines - Porter occupational scale (Blishen, 1967). The resulting Socio-Economic Index covers 320 occupations, ranging from Chemical Engineer (76.69), Dentist (76.44), and Professor (76.01) to Shoemaker (26.56), Fish Canners (26.09), and Trappers (25.36).

The data from the Wellington Junior High School District is compared with that of Alberta and Canada in Table I. The Wellington area

TABLE I

COMPARISON OF WELLINGTON JUNIOR HIGH SCHOOL DISTRICT
WITH ALBERTA AND CANADA
USING BLISHEN'S SOCIO-ECONOMIC INDEX

SOCIO-ECONOMIC INDEX	PERCENTAGE OF LABOUR FORCE WELLINGTON	ALBERTA	CANADA
70+	3	7	4
60 - 69	7	4	4
50 - 59	7	10	9
40 - 49	20	20	20
30 - 39	44	29	32
Below 30	19	33	31

Note: Alberta and Canada figures are based on the 1961 Census.

had a mean Socio-Economic Index value of 39.15, with a standard deviation of 11.68. This compares with the Alberta figure of 39.20, standard deviation 12.64 and a Canadian value of 38.81, standard deviation 12.19. The results are supportive of the statement that the socio-economic background of the Wellington area is similar to those of both Alberta and Canada.

II. DESCRIPTION OF THE IBM 1500 INSTRUCTIONAL SYSTEM

The IBM 1500 Instructional System is a computer controlled system of remote terminals and peripheral devices that has been designed to provide computer-assisted instruction for students. The main computer is an IBM 1130 with 65,000 characters of core memory supplemented with about five million characters of on-line disc storage. There are two magnetic tape units which can provide virtually unlimited storage capacity.

The system is capable of handling thirty-two student terminals which interact with the IBM 1130 on a time-sharing basis. The present system operated by the Division of Educational Research Services at the University of Alberta has eighteen terminals. Sixteen terminals consist of a cathode-ray display screen (CRT), a light-pen, a keyboard, an image projector, and an audio unit. The two remaining terminals are remote typewriter devices. Fifteen of the complete student terminals plus one of the remote typewriters are located in one room, where students take the various courses that are available.

Since the System is based on time-sharing, student performance at each terminal is independent of the other terminals. Thus each student may be taking a different course or all of the students may be at different positions in the same course. A student at a terminal gains the impression that the resources of the computer are being devoted specifically to his requirements since appropriate messages are displayed within a couple of seconds of his individual responses.

III. DESCRIPTION OF SIMULATION GAME

The computer program, called FISHY, that was used in this study simulates the salmon fishing industry of British Columbia. The program was written in a language called COURSEWRITER II for use on the IBM 1500 Instructional System. A copy of the program documentation for FISHY may be found in Appendix B.

The initial frames (CRT lay-outs) provide a general description on the importance of the fishing industry in Canada. There are 8 such frames preceeding the actual start of the simulation game. Thus the initial introduction to the game consists of the following sequence of frames:

frame 1: The fishing industry has always played an important role in the economic development of Canada. Although the fishing industry has declined in relative importance in the overall economy, Canada remains one of the world's leading fishing nations.

frame 2: This game is about the salmon fishing industry in British Columbia. Salmon is, by far, the most important fish found in British Columbia waters. Because salmon is high in food value and is easily canned, British Columbia salmon is sold all over the world.

frame 3: There will be some lighted squares (like this, ▨) on the screen. These squares, or 'targets', will always follow a short description of the type of decision they stand for.

frame 4: To make a decision:

1. Point the light pen at the target, ▨ , that indicates the type of variable that you want to change.

2. A question will then appear at the bottom of the screen. You will then type in a number that gives the amount of change you want to make.

That is, a decision requires 2 steps:

Step 1. Indicate what you want changed.

Step 2. Type how much the change will be.

frame 5: After you have made your decisions for a 'year', point the light-pen to the target after the word 'END'. This indicates the end of the 'year'. The results of your decisions will then appear on the screen and you will be ready to start making decisions for the new 'year'. To continue, point the light-pen at the target after the word 'END'.

END

frame 6: Please remember that this exercise will have many of the changes that would actually occur in a major industry. Thus one would expect that there will be a number of changes that will occur in addition to the decisions that you make.

frame 7: For example, equipment will depreciate in value, men will leave their jobs, raises in salaries may occur, the health of the salmon population will depend on the quality of its environment (which in turn is affected by the importance of fish ladders and pollution control measures), and the market for fish will vary depending on world-wide conditions. Thus in general it may be said that the industry will always be in a state of change.

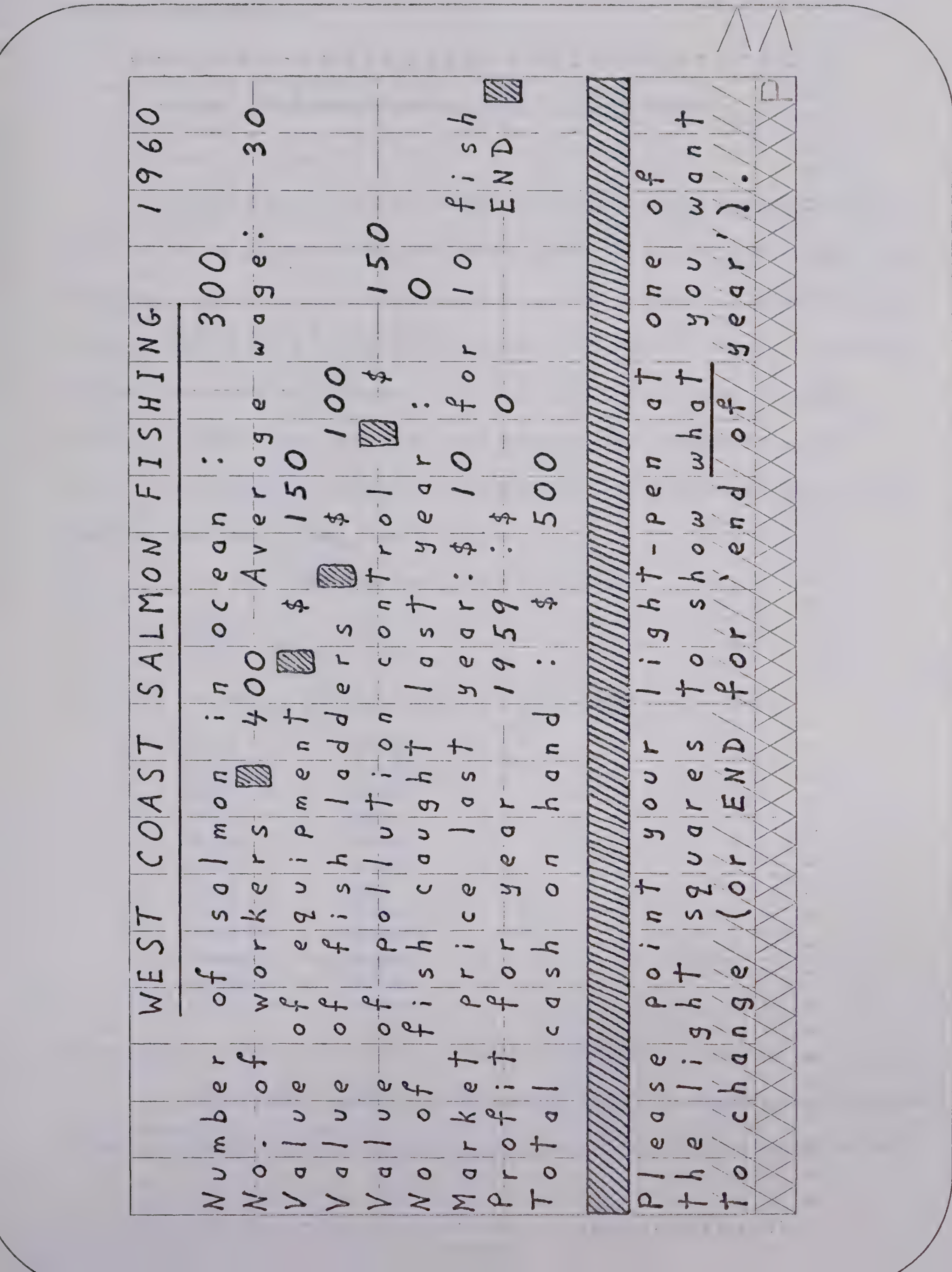
frame 8: Note: The numbers used in the game are much smaller than in the real fishing industry. This should help to make the game easier. Since the value of your decisions will affect the amount of money you will make, your 'score' will be the total cash on hand. The game will last for a period of 10 years, from 1960 until 1970. Type in the year '1960' to start the game. GOOD LUCK and GOOD FISHING!

The next frame is pictured in Figure 1, which represents the actual CRT-layout used for the entire game.

Thus the student could change the number of workers (by hiring or laying-off), or add to the value of equipment, fish ladders, or pollution control. Decisions involving monetary values were immediately recorded by an appropriate increase in the indicated variable and a corresponding decrease in the cash on hand. When the student pointed his light pen at the target following the word END, the following message was displayed at the bottom of the screen, "The calculations for the current year are now being performed. Notice that the values displayed above will now change. Press space bar to see changes". The actual equations used in

FIGURE 1

CRT LAYOUT FOR SIMULATION GAME 'FISHY'



the simulation model are included in the program documentation for FISHY, found in Appendix B.

IV. DESCRIPTION OF COMPUTER-BASED MFF TEST

This program, called FIGUR, provides a computer-based presentation of Jerome Kagan's (1966a) Matching Familiar Figures (MFF) test. This test may be used to provide measures on an "Impulsivity - Reflectivity" scale. This version of the test requires a student to select a matching figure from among six choices. For each trial the student is shown a picture of one figure separated from a set of six figures by a solid line. The student is required to select the figure from the set of six that is identical to the single figure.

The test contains two practise trials:

Trial 1 : cups
Trial 2 : rulers

Following are twelve trials, presented in the order:

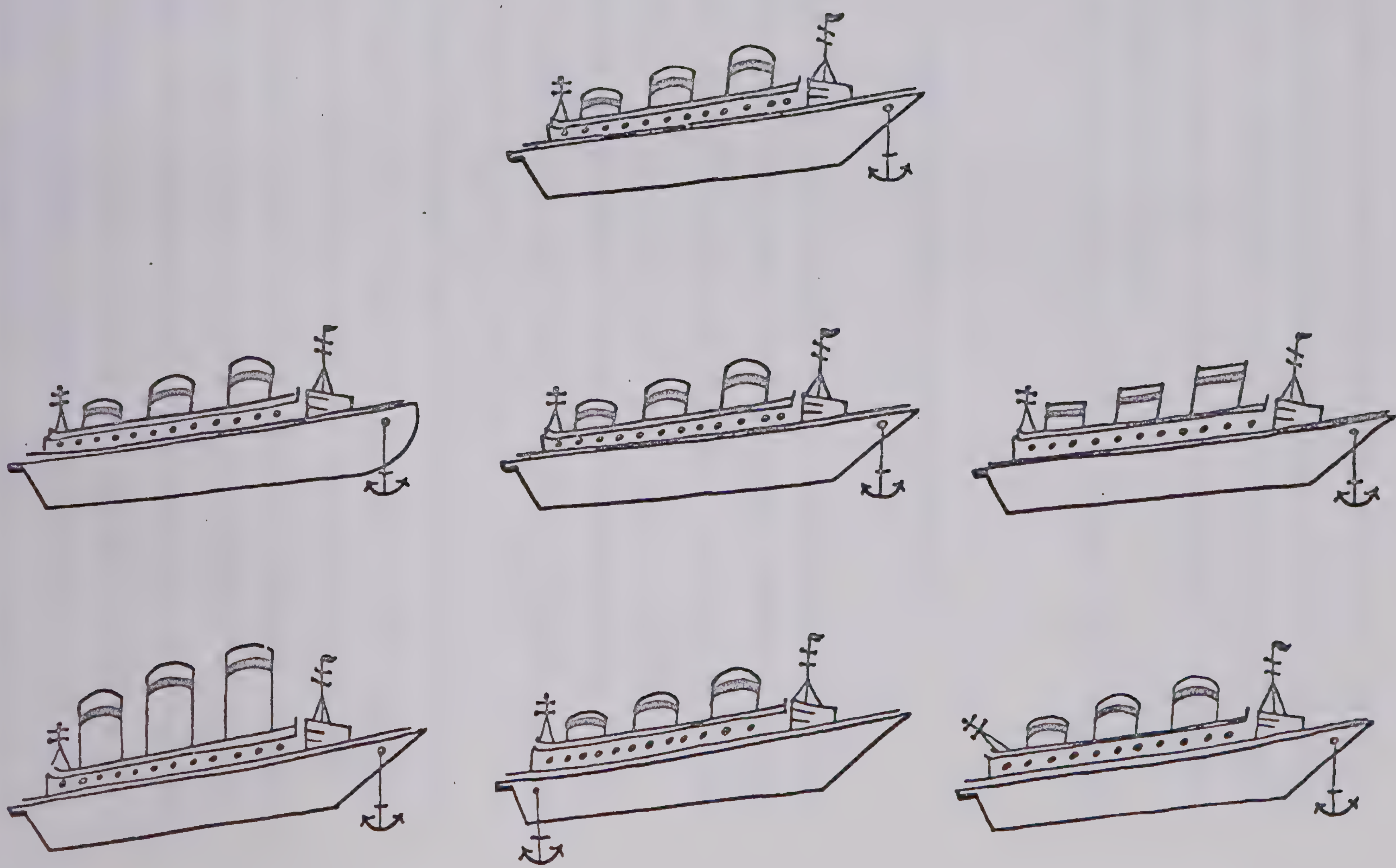
Trial 3 : houses
Trial 4 : scissors
Trial 5 : phones
Trial 6 : bears
Trial 7 : trees
Trial 8 : leaves
Trial 9 : cats
Trial 10 : dresses
Trial 11 : animals
Trial 12 : lamps
Trial 13 : boats
Trial 14 : cowboys

An example of one of the trial pictures is provided in Figure 2.

If a student selects an incorrect choice during the two practise trials a message is displayed giving the reason why he was wrong and he

FIGURE 2

SAMPLE ITEM FROM MATCHING FAMILIAR FIGURES TEST



is branched back to the same problem and asked to try again. If he is correct he receives confirmation and is branched to the next problem in the sequence. The same pattern is repeated for the next twelve trials except if he is incorrect he is merely told to try again - no message is given explaining why he was wrong.

A copy of the program documentation for FIGUR may be found in Appendix C.

V. STUDENT PERFORMANCE ON COMPUTER TERMINALS

Each subject was assigned to one of six groups, each group containing either 12 or 13 subjects. The grouping was necessary for scheduling reasons on the IBM 1500 Instruction System - which has only 16 student terminals. The groups were formed on the basis of the order of occurrence of the random numbers used in the selection procedure. Thus the first 12 random numbers were used to form group 1, the next 12 random numbers were used to form group 2, and so on.

In order to decrease the initial unfamiliarity with the system and to help familiarize the students with the method of "inputting" responses, each of the students selected for the study was given a brief description entitled, "Student Use of the Computer Terminals". A copy of this description may be found in Appendix D. The student's ability to use the terminal was tested during the initial frames of the course which required the student to respond by using the light-pen and then the keyboard. If the student failed to respond within a period of 100 seconds for the light-pen or 120 seconds for the keyboard, a message was printed

out at the typewriter terminal indicating the student that was having difficulty. A summary of the frequency of occurrence of these messages for human intervention is given in Table II. Approximately half of the students required no further assistance using the terminals. Those students experiencing difficulty were given additional help so all students were familiar with the use of the terminals before the actual simulation game began.

After each student had demonstrated that he could use the terminal the actual simulation game began. Some of the students were confused at the start of the game about what was required. However the nature of the decision making was reviewed with these students and after the pattern of one or two decisions was established no further difficulties were encountered. The results of the students decisions were evaluated when the student indicated 'end of year' and the process was continued for ten cycles or 'years'. After 10 years, a summary of the student's cash-on-hand at the end of each year was displayed on the screen.

The computer program then branched to a new course segment which consisted of a computer-based version of Kagan's (1966a) Matching Familiar Figures test. There was an initial problem with some of the terminal image projectors - the pictures were out of focus. However this was corrected during the two pre-test trials and should not have appreciably affected the later results, although a difference in the sharpness of the images was observed among some of the terminals.

Since the students proceeded through both the simulation game and the MFF test at individual speeds, the students completed this portion of the study at different times. Tables III and IV give the elapsed

TABLE II

FREQUENCY OF INITIAL DIFFICULTIES
USING THE COMPUTER TERMINALS

GROUP	LIGHT-PEN RESPONSE ONLY	KEYBOARD RESPONSE ONLY	BOTH	NO DIFFICULTIES
1	3	4	2	3
2	0	1	2	5
3	2	2	0	7
4	2	1	2	6
5	1	1	0	11
6	1	3	4	4
Totals:	9	12	10	36

TABLE III

SUMMARY OF ELAPSED TIMES FOR STUDENTS
ON THE SIMULATION GAME, 'FISHY'

Group	N	Lowest	MINUTES Highest	Range	Mean	S. D.
1	12	34.12	65.06	30.94	51.28	8.60
2	8	29.62	57.24	27.62	43.68	8.46
3	11	27.02	65.49	38.47	46.34	12.42
4	11	25.52	61.07	35.55	45.20	9.03
5	13	27.76	51.29	23.53	38.77	8.84
6	12	42.60	60.95	18.35	47.45	5.60
Totals:	67	25.52	65.49	39.97	45.45	9.86

TABLE IV

SUMMARY OF ELAPSED TIMES FOR STUDENTS ON THE MFF TEST

Group	N	MINUTES Lowest	Highest	Range	Mean	S. D.
1	12	5.19	17.44	12.25	10.38	3.12
2	8	5.51	15.25	9.74	10.01	3.00
3	11	6.07	15.31	9.24	11.05	2.48
4	11	5.36	14.36	9.00	9.02	2.78
5	13	6.93	18.13	11.20	10.82	3.00
6	12	5.84	16.79	10.95	10.55	3.28
Totals:	67	5.19	18.13	12.94	10.34	3.03

times for the two computer programs illustrating the individual differences among students using computer-assisted instruction. In order to minimize classroom disruption and to avoid putting a "hurry-up" pressure on the slower students, the students were given a demonstration course when they finished the MFF test. Thus all students remained on the terminals until the last student had completed the MFF test.

VI. ADMINISTRATION OF MARKER TESTS FOR COGNITIVE FACTORS

The tests selected from the Kit of Reference Tests for Cognitive Factors (French, Ekstrom, and Price, 1967) were given at Wellington Junior High School the week following the students' use of the computer terminals. The students were divided into two groups on the basis of their home classroom in order to minimize the disruption of the normal school schedule. Thus students from classes 8A to 8E were tested during the morning and students from 8F to 8J received their tests during the afternoon of the same day. It took approximately 2 hours and 20 minutes to administer the 10 tests to each group.

The following pre-test instructions were read to each group:

1. This is the second part of the study.
2. It is not expected that you will finish all of the tests - the same tests are used with adults - but please do as well as you can.
3. All results will be known only to myself and all results will be kept completely anonymous.
4. There will be a set of 10 tests.
5. Each test will have a page of instructions followed by two or more actual test pages.

6. All tests will have time limits - clearly indicated beforehand.
7. Open your envelopes. Be sure to keep the tests in order.

The testing then proceeded with the tests given in the following order:

1. Vocabulary Test (V-2)
2. letter Sets Test (I-1)
3. Subtraction and Multiplication Test (N-3)
4. First and Last Names Test (Ma-3)
5. Mathematics Aptitude Test (R-1)
6. Figure Classification (I-3)
7. Addition Test (N-1)
8. Object-Number Test (Ma-2)
9. Necessary Arithmetic Operations Test (R-4)
10. Vocabulary Test (V-1).

Thus any fatigue effect should distribute itself over the different factors.

The students read the instructions for one test while the results from the previous test were being collected. The students were asked if they had any questions on the nature of the test - if there were none the first timed section was begun. The only confusion regarding the instructions was with test, Figure Classification (I-3), which required further explanation for both groups.

Upon completion of the formal testing, the students were asked to indicate on a 7-point scale, where a 1 represented DISLIKE and a 7 represented LIKE, their position with regard to the following questions:

1. Indicate on the scale your feelings about taking part of your school curriculum on a computer terminal.

2. Indicate on the scale your feelings about the game FISHY.

3. Did you find the testing session today too long? Answer yes or no.

4. Did you find the testing session today too hard? Answer yes or no.

The next chapter will give the statistical analysis and results of the data that was collected according to the procedures outlined in this chapter.

CHAPTER IV

STATISTICAL ANALYSIS AND INTERPRETATION OF RESULTS

I. COMPONENT CURVE ANALYSIS OF STUDENT PERFORMANCE

The raw data for each subject used in the component curve analysis consisted of the values of the "cash on hand" variable from the simulation game FISHY over the 10 "years", or trials, of operation. Since the identification of individual differences in performance is an important feature of this study, the raw data are given in Table V in order to facilitate later comparisons with some of the derived measures.

Mean Cross Product Matrix - Unrotated Solution

The scale for the "cash on hand" variable was modified prior to the actual analysis by multiplying all values by 0.10. This reduces the magnitude of the reported values without altering the nature of the results. The method of component curve analysis was applied to the mean cross product matrix formed from this data. The mean square ratios, reported in Table VI, were used to determine the number of characteristic vectors required to reproduce the original data. Assuming that these mean square ratios are approximately distributed as the F distribution, a decision was made to retain 4 characteristic vectors. Each successive curve shows an increasing amount of fluctuation, however the first four characteristic vectors are sufficiently "smooth" to permit a learning curve interpretation. These curves are illustrated in Figures 3 - 6.

The next step in the analysis computed the loadings of the

TABLE V

STUDENT DATA FROM SIMULATION GAME 'FISHY'
(X MATRIX)

Subject ID.	Value of 'Cash on Hand' Variable after Each 'Year' (Trial) 1	2	3	4	5	6	7	8	9	10	Average
1	199	188	97	104	97	114	99	110	106	98	121
2	445	272	215	105	57	134	174	209	192	145	194
3	504	512	527	528	511	485	459	436	400	356	471
4	158	133	110	138	159	185	163	206	218	129	159
5	509	512	418	401	379	363	349	333	320	300	388
6	508	449	354	290	324	343	350	341	306	309	357
7	424	422	362	352	250	301	396	388	260	117	327
8	303	243	137	65	106	64	80	100	94	53	124
9	512	520	431	414	384	355	337	311	294	272	383
10	64	92	100	153	188	182	155	196	212	200	154
11	373	366	259	251	242	233	225	117	108	99	227
12	124	179	95	99	82	39	47	68	61	23	81
13	402	446	479	384	341	337	335	333	292	292	364
14	316	122	126	114	104	88	79	70	55	40	111
16	350	347	194	147	21	-1	-28	-55	-89	-123	76
17	413	490	522	560	555	619	644	692	752	787	603
18	480	195	259	280	325	366	408	428	454	485	368
19	348	312	321	328	318	311	302	279	254	213	298
20	390	309	242	114	76	43	50	49	52	54	137
21	393	359	339	271	281	287	345	366	383	336	336
24	353	329	347	359	375	376	372	373	359	352	359
25	413	368	360	378	382	377	258	305	289	280	351
26	524	541	383	371	314	78	95	151	220	210	288
27	460	435	435	423	414	418	429	467	481	481	444
28	417	428	432	421	395	377	345	307	265	251	363
31	410	396	425	452	471	494	525	574	603	641	499
32	388	405	465	503	539	558	551	571	585	410	497
33	355	362	359	0	0	0	0	0	0	0	107
34	64	42	37	26	5	0	0	0	0	0	17
35	509	510	504	500	481	468	455	428	393	374	462
36	509	507	432	400	350	314	276	257	233	191	346
37	93	63	122	172	163	231	292	283	271	328	201
38	63	71	77	117	33	34	14	0	0	0	40
39	471	471	477	489	498	490	487	477	541	599	500
40	98	0	0	0	0	31	27	19	9	0	18

TABLE V (continued)

Subject ID	Value of 'Cash on Hand' Variable after Each 'Year' (Trial) 1	2	3	4	5	6	7	8	9	10	Average
41	403	345	267	299	289	252	154	143	144	141	243
42	211	195	211	204	190	178	151	128	93	71	163
43	459	458	440	405	362	377	382	374	375	372	400
45	240	203	206	123	89	86	80	70	51	34	118
46	236	204	160	152	118	110	91,	87	70	47	127
47	395	387	422	399	385	345	240	248	137	163	312
48	287	331	379	413	451	475	498	517	476	479	430
49	393	412	430	434	439	451	448	441	427	416	429
51	475	486	486	482	460	456	455	439	407	389	453
52	412	414	454	482	510	524	530	524	510	502	486
53	391	418	462	504	524	533	533	517	523	525	493
54	219	39	9	5	0	0	0	0	0	0	27
55	511	502	488	322	184	21	0	0	0	0	202
56	508	521	526	466	496	562	574	589	601	598	544
57	394	399	401	447	478	555	619	641	652	656	524
58	338	277	194	142	141	139	138	144	101	85	169
59	16	9	5	0	0	0	0	0	0	0	3
60	41	24	33	19	2	0	0	0	0	0	11
61	508	456	462	454	442	406	352	325	221	244	387
62	528	349	165	291	389	472	525	525	590	617	445
63	373	262	281	301	211	155	159	119	45	52	195
64	514	119	109	92	42	25	0	0	0	0	90
65	506	290	21	0	0	0	0	0	0	0	81
66	361	368	352	395	417	429	448	456	443	418	408
67	195	248	231	74	68	86	106	122	108	139	137
68	514	462	416	444	460	458	448	452	454	451	455
69	220	91	8	0	180	208	116	118	37	32	101
70	519	547	256	278	391	466	431	377	144	137	354
72	396	429	507	368	295	229	247	176	125	137	290
73	513	444	446	307	277	60	42	27	8	0	212
74	509	314	287	295	304	298	326	336	346	342	335
75	502	507	508	576	475	497	578	531	618	686	547
N = 67											
Mean Value	365	327	299	282	273	268	267	263	249	239	

TABLE VI

COMPONENT CURVE ANALYSIS OF MEAN CROSS PRODUCT MATRIX

MEAN SQUARE RATIOS

Component	Eigenvalue	df1	df2	Mean Square Ratio
1	10692.39	76	594	111.28
2	554.08	74	520	19.77
3	92.82	72	448	5.55
4	50.92	70	378	5.17
5	22.81	68	310	3.42
6	13.18	66	244	2.83
7	8.08	64	180	2.49
8	5.62	62	118	3.05
9	2.09	60	58	1.43
10	1.42	58	0	0

FIGURE 3

CHARACTERISTIC VECTOR 1

MEAN CROSS PRODUCT SOLUTION

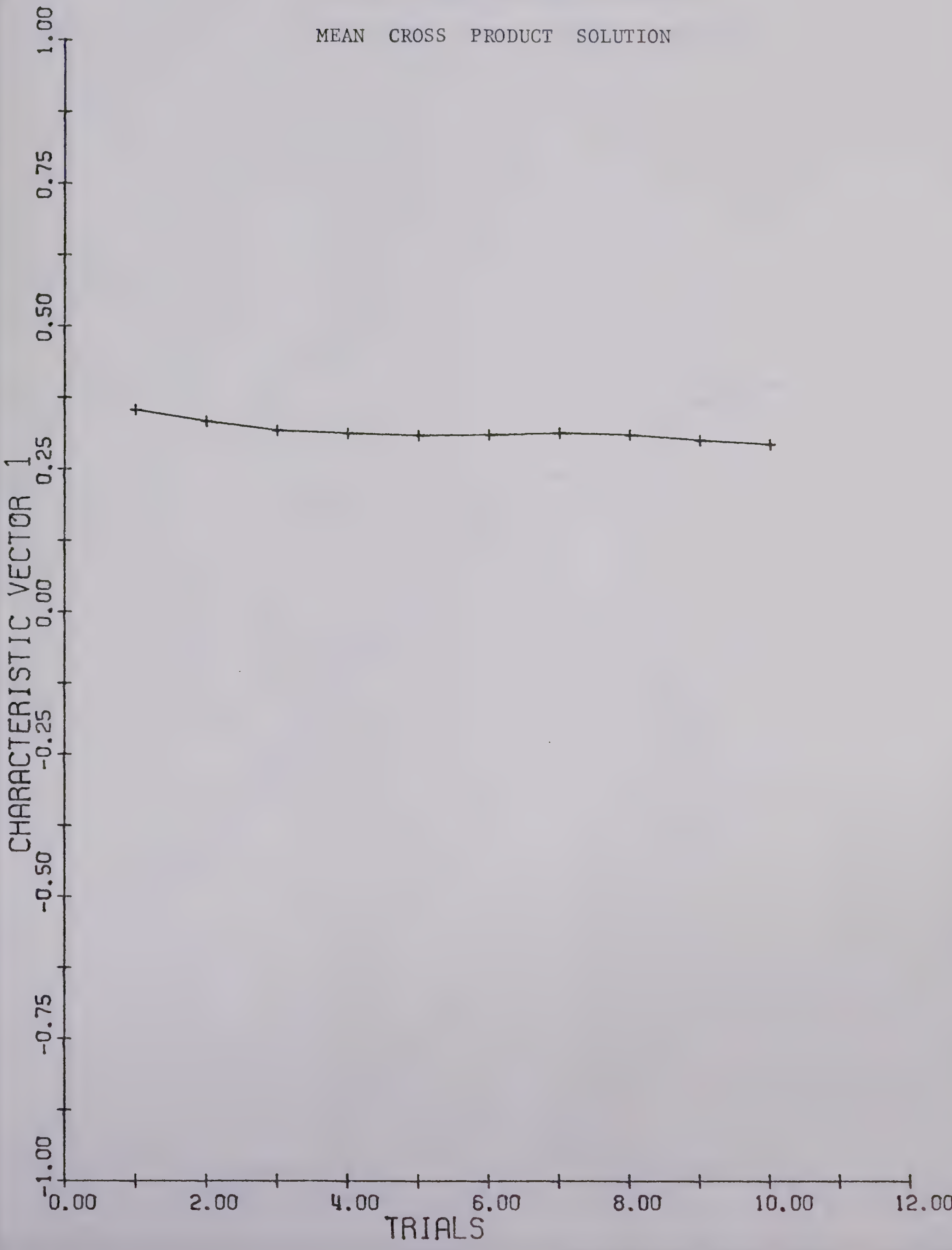


FIGURE 4

CHARACTERISTIC VECTOR 2

MEAN CROSS PRODUCT SOLUTION

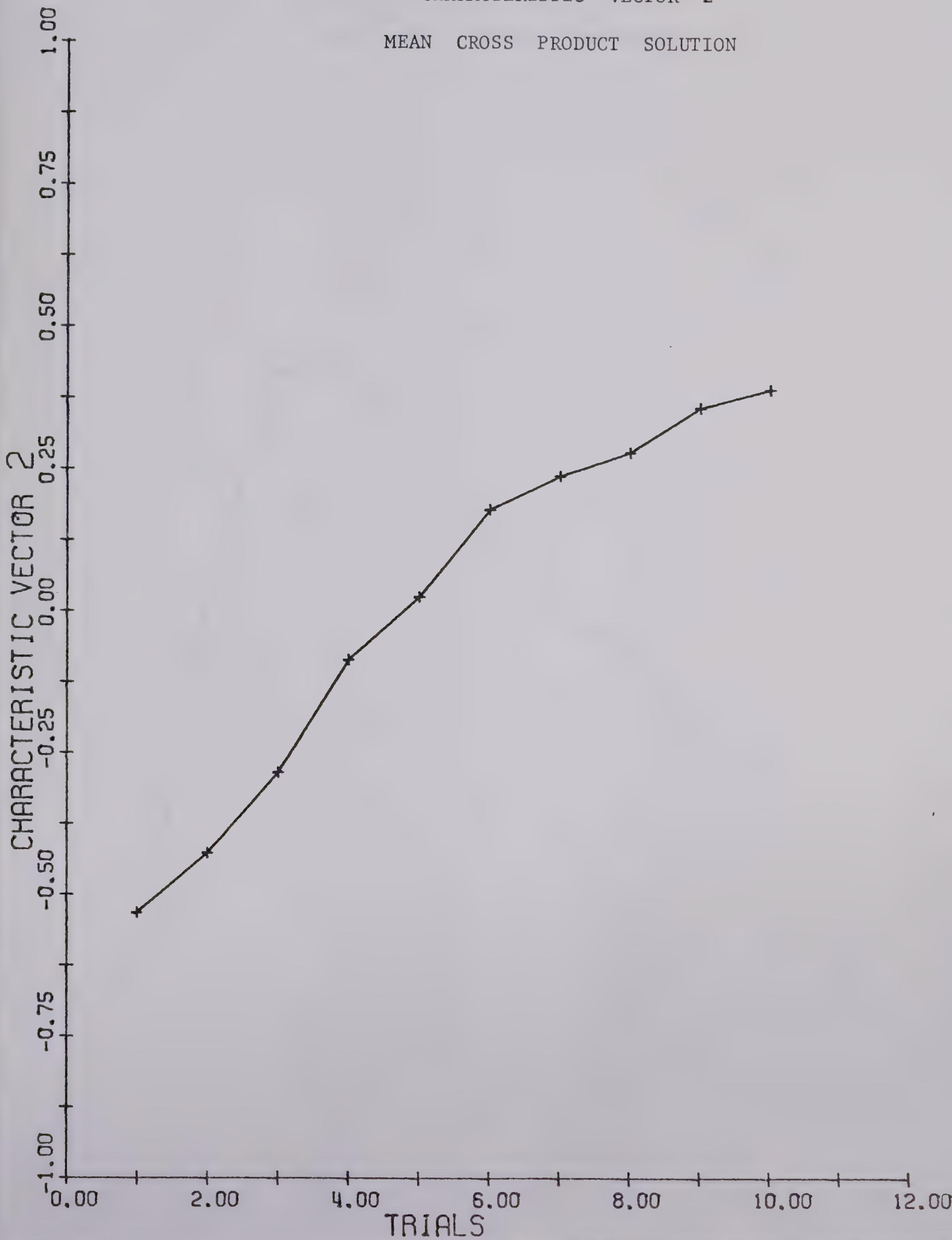


FIGURE 5

CHARACTERISTIC VECTOR 3

MEAN CROSS PRODUCT SOLUTION

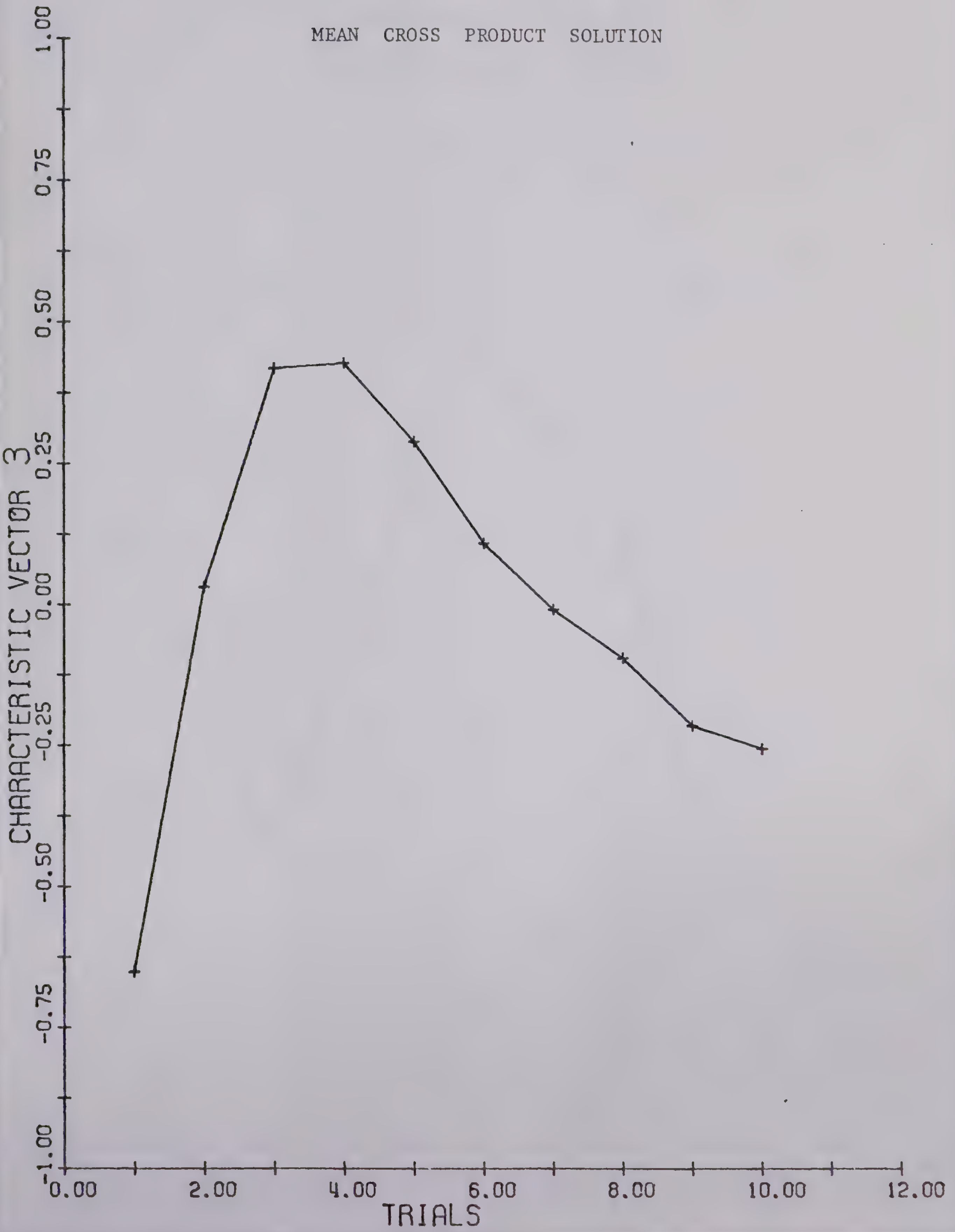
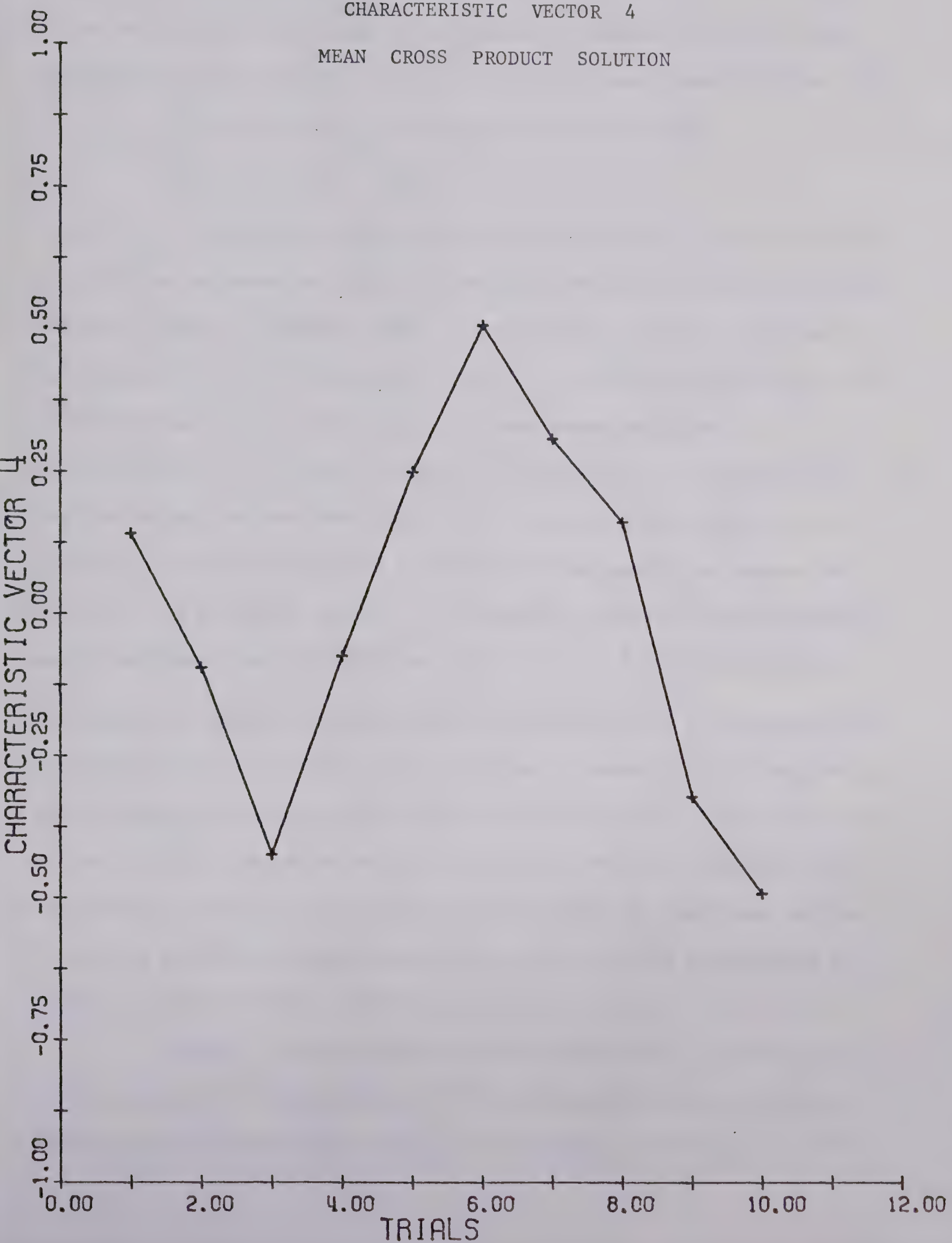


FIGURE 6

CHARACTERISTIC VECTOR 4

MEAN CROSS PRODUCT SOLUTION



component curves for each of the 10 trials. The results are given in both tabular (Table VII) and graphical (Figure 7) form. The last step in the unrotated solution was to calculate the factor scores for each individual on each component curve. The results are found in Table VIII.

Since component curve analysis uses the model,

$$\hat{X}_{ji} = b_{j1} Y_{1i} + b_{j2} Y_{2i} + \ldots + b_{jk} Y_{ki}$$

where $\hat{X}_{ji}$ is the estimated score on trial j for person i, it is possible to obtain an estimate for any X_{ji} from the B_k^* matrix of component weights and the Y_k^* matrix of factor scores. For example, subject 1 on trial 1 had a value of 19.9. Using values from row 1 of Table VII and row 1 of Table VIII, and substituting into the above equation, gives

$$(36.55)(0.375) + (-12.52)(-0.293) + (-6.28)(-0.590) + (1.01)(0.133) = 21.2.$$

The discrepancy between the value of 21.2 and the actual value of 19.9 is a result of using 4 components instead of 10 components to compute the estimate. In a similar manner it is possible to compute the complete $\hat{X}_k$ matrix and then form a residual matrix, $X_{r_k} = X - \hat{X}_k$. This difference represents one method of determining how well the first k components can reproduce the original data matrix. Instead of examining the complete residual matrix, it is more desirable to refer to the mean square ratio developed by Tucker which compares the square of the k th eigenvalue with the sums of squares of the remaining eigenvalues. As explained earlier, this ratio provides an approximate statistical test for determining the number of components that should be retained.

However the principle interest centers about two other focal points, namely the "meaningfulness" of the component curves and their differentiating ability with respect to individual performances. The

TABLE VII

COMPONENT CURVE ANALYSIS OF MEAN CROSS PRODUCT MATRIX

LOADINGS OF TRIALS ON COMPONENT CURVES

(B_k^* MATRIX)

Trial 'Year'	Component Curves 1	2	3	4
1	36.55	-12.52	-6.28	1.01
2	34.54	-10.03	0.30	-0.67
3	32.88	- 6.68	4.04	-3.03
4	32.40	- 2.00	4.13	-0.52
5	32.02	0.60	2.79	1.78
6	32.10	4.22	1.05	3.61
7	32.41	5.60	-0.08	2.20
8	32.10	6.58	-0.91	1.15
9	31.14	8.42	-2.07	-2.30
10	30.43	9.18	-2.46	-3.51

FIGURE 7

UNROTATED COMPONENT CURVES

MEAN CROSS PRODUCT SOLUTION

(The dots represent trial means)

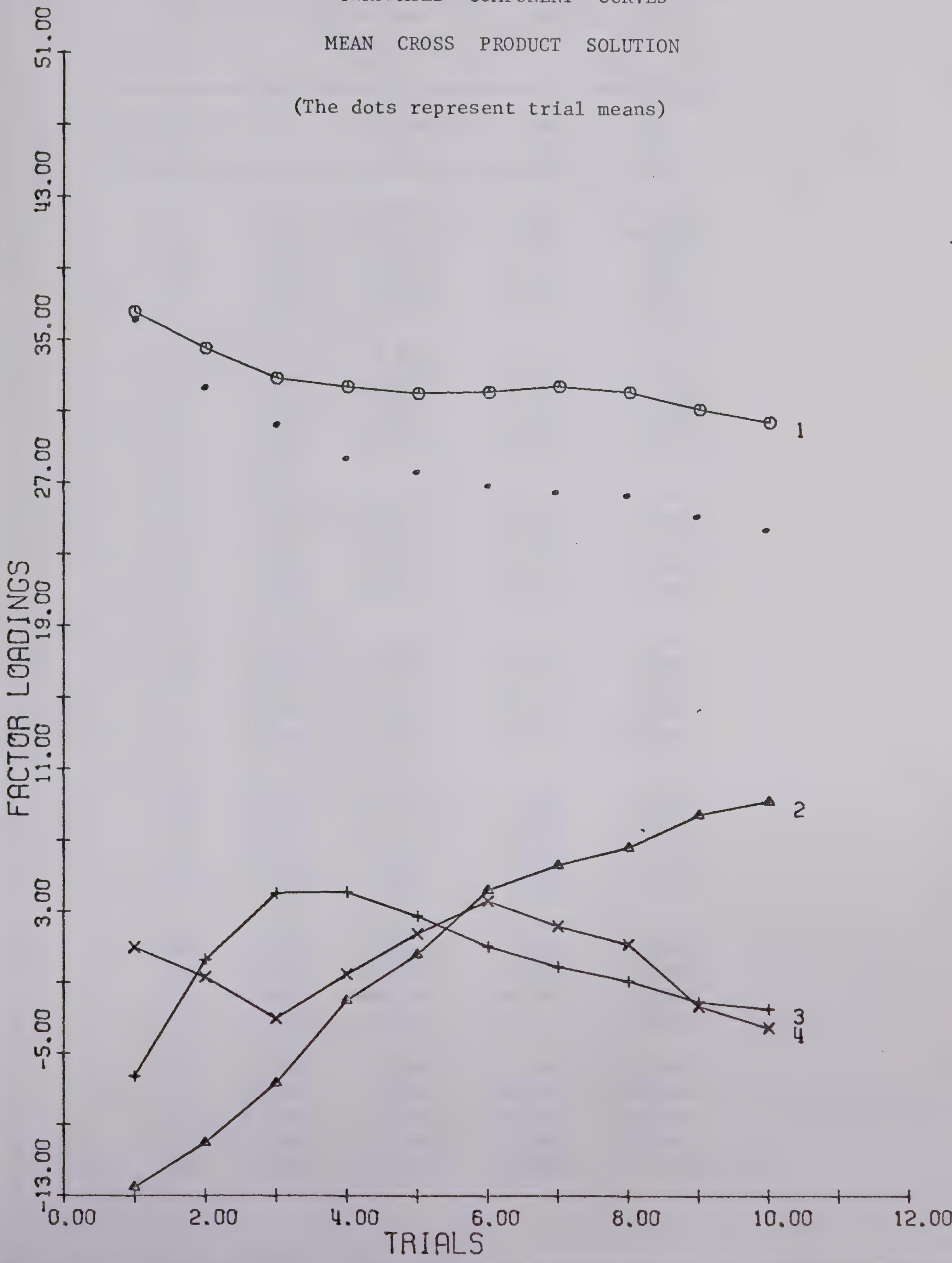


TABLE VIII

COMPONENT CURVE ANALYSIS OF MEAN CROSS PRODUCT MATRIX

FACTOR SCORES ON UNROTATED COMPONENT CURVES

($Y_k^{*'}$ MATRIX)

Subject ID	I	II	III	IV
1	0.375	-0.293	-0.590	0.133
2	0.608	-0.731	-2.223	-0.356
3	1.446	-0.288	1.189	0.583
4	0.487	0.332	-0.287	0.507
5	1.196	-0.677	0.018	0.083
6	1.101	-0.461	-0.957	0.348
7	1.010	-0.580	0.203	1.386
8	0.392	-0.823	-1.146	0.005
9	1.181	-0.849	0.275	0.158
10	0.464	0.715	0.278	-0.021
11	0.707	-1.010	0.197	1.024
12	0.255	-0.457	0.097	-0.171
13	1.118	-0.477	0.850	-0.583
14	0.351	-0.737	-0.932	0.563
16	0.256	-2.137	-0.113	0.002
17	1.828	1.798	0.012	-1.650
18	1.121	0.877	-2.165	-0.064
19	0.916	-0.210	0.485	0.671
20	0.438	-1.456	-1.009	-0.901
21	1.029	0.126	-0.818	-0.699
24	1.097	0.333	0.254	0.215
25	1.077	-0.215	0.438	0.815
26	0.900	-1.709	-0.218	-2.373
27	1.356	0.374	-0.312	-0.850
28	1.118	-0.529	1.104	0.574
31	1.515	1.298	-0.452	-1.126
32	1.513	0.934	1.029	1.000
33	0.349	-1.891	-0.719	-1.909
34	0.056	-0.274	-0.127	-0.158
35	1.417	-0.269	0.797	0.408
36	1.074	-1.202	0.493	0.216
37	0.606	1.246	-0.333	-0.176
38	0.128	-0.362	0.589	-0.130
39	1.523	0.631	-0.025	-1.200
40	0.059	-0.134	-0.668	0.533

TABLE VIII (Continued)

Subject ID	Component Curves I	II	III	IV
41	0.756	-0.964	0.188	0.614
42	0.504	-0.438	0.703	0.656
43	1.228	-0.201	0.061	-0.549
45	0.371	-0.830	-0.026	-0.183
46	0.398	-0.675	-0.050	0.234
47	0.963	-0.927	1.616	1.003
48	1.306	1.190	0.672	0.269
49	1.309	0.396	0.589	0.103
51	1.388	-0.073	0.702	0.197
52	1.480	0.816	0.575	0.287
53	1.499	0.900	0.820	0.062
54	0.092	-0.578	-1.406	0.324
55	0.646	-2.733	0.842	-2.090
56	1.658	0.771	-0.320	-0.591
57	1.589	1.681	-0.601	-0.324
58	0.530	-0.825	-0.739	0.364
59	0.010	-0.058	-0.083	-0.010
60	0.038	-0.183	-0.035	-0.159
61	1.193	-0.856	1.047	1.193
62	1.355	1.345	-3.243	0.551
63	0.611	-1.168	0.568	0.645
64	0.296	-1.518	-2.398	0.444
65	0.273	-1.694	-3.234	0.495
66	1.245	0.682	0.131	0.317
67	0.426	-0.476	-0.337	-1.255
68	1.395	0.165	-0.321	0.135
69	0.314	-0.127	-0.938	2.754
70	1.099	-0.846	-0.364	4.291
72	0.902	-1.334	1.618	-0.562
73	0.673	-2.450	0.836	-0.936
74	1.031	-0.091	-1.558	0.010
75	1.667	0.847	-0.224	-1.923

N = 67

first point may be investigated by examining the B_k^* matrix of factor loadings; the second point requires focusing on the Y_k^* matrix of factor scores.

The nature of the unrotated component curves is easily visualized by referring to Figure 7. Component 1 is fairly close to the trial means. In this sense it may be said to represent the "average learning curve" - a concept which may or may not be of value.

The remaining curves are a measure of the degree to which the average learning curve failed to account for the observed data. Thus the approximate average learning curve failed to represent a performance of strong increase, as shown by component 2 (or of strong decrease - if a person has a negative factor score on this component). For example, subjects 16, 55, and 73 have a low factor score on component 1 and a high (negative) factor score on component 2. A review of their actual performance (Table V) shows the close agreement between a description based on component curves and a description based on raw data. Similar statements may be made for components 3 and 4.

It is possible to provide a verbal description for each of the components based on their shape. However it is important to note that each curve may be considered to represent two possibilities corresponding to the positive and negative factor scores on the components. Thus component 1 represents a slow drop in performance over the 10 trials, component 2 shows a strong steady increase (decrease) over the 10 trials, component 3 has a strong initial increase (decrease) for 3 trials followed by a gradual decrease (increase) for the remaining 7 trials, and component 4 shows a decrease (increase) for 3 trials, then an increase (decrease) for 3 trials, followed by a gradual decrease (increase) over the

last 4 trials. Thus the first three components allow for a reasonably meaningful learning interpretation with the fourth component representing a more erratic performance.

The second main point of interest focuses on the issue of individual differences. The critical question appears to be, "To what extent may subjects be uniquely identified with a single (unrotated) component curve?". An examination of the factor scores on the component curves appears appropriate. One should note that a factor score on a particular component is independent of whether the component accounts for 80% or 5% of the variance. The factor scores for each component curve are standardized with a mean of zero and standard deviation of one. Using a criterion that the factor score with the largest magnitude must be at least double the magnitude of the next largest factor score, a review of Table VIII suggests that subjects 5, 24, 43, 49, 56, and 68 are strongly associated with component 1; subjects 16, 37, and 73 with component 2; subjects 2, 54, 62 and 65 with component 3; and subjects 67, 69, and 70 with component 4. Therefore a total of 16 subjects out of 67 or 24% of the subjects may be uniquely identified with a single component. Thus the unrotated solution does not appear to exhibit a strong simple structure in the person space.

This finding may be the result of an interaction between the level of complexity of the task and the ability characteristics of the subjects. Thus if a perfect simple structure was observed in the factor score matrix for the four components, it would imply that the subjects may have used four clearly defined patterns of performance. The actual results show the untenability of this position - instead there are a large number of possible patterns of performance, each pattern being approximated

by a set of four factor scores.

Mean Cross Product Matrix - Orthogonal Rotations

It is a property of factor analysis that there are an infinite number of solutions that may account for the observed data equally well. Thus it has become common practise to search for a method of rotation which will lead to some optimal "psychologically meaningful" solution. The same mathematical properties are true of component curve analysis.

Any rotation may be expressed in matrix notation by the use of a transformation matrix, T, where

$$B_k^* \; T = B_k^r$$

$$T^{-1} \; Y_k^* = Y_k^r \; .$$

Note that any rotation does not change the estimates of the original data matrix, since

$$\begin{aligned} \hat{X}_k &= B_k^* \; Y_k^* \\ &= B_k^* \; TT^{-1} \; Y_k^* \\ &= B_k^r \; Y_k^r \; . \end{aligned}$$

A general class of normalized orthogonal rotations is given by the following criterion:

$$n \sum_{j=1}^{n} \sum_{p=1}^{m} \left(\frac{b_{jp}}{h_j} \right)^4 - w \sum_{p=1}^{m} \left(\sum_{j=1}^{n} \frac{b_{jp}^2}{h_j^2} \right)^2 = \text{maximum},$$

where b_{jp} is the loading of variable j (j = 1, 2, ..., n) on the orthogonal factor p (p = 1, 2, ..., m). There is evidence (Hakstian and Boyd, 1970) to suggest that as the parameter w is increased, the variance dispersion amon the factors tends to become more equal. The values of 0, 1, and $^m/2$ for w correspond to the well-known rotations quartimax, varimax,

and equamax.

The three rotations quartimax, varimax, and equamax were applied to the factor score matrix Y_k^* . The component curves corresponding to these rotations are given in Figures 8 - 10. Since these rotations are all designed to improve the simple structure of the input matrix, they represent a direct approach for improving the extent to which subjects may be uniquely identified with a single component curve.

A review of an earlier section, Issue on Rotation of Axes, indicates that two criteria are to be used for evaluating the results of a particular rotation; the meaningfulness of the resulting curves based on a subjective evaluation of the smoothness and general shape of the rotated curves, and the increase in ability to distinguish among the subjects using the scores on the rotated curves.

First consider the criterion of maximum separation among the subjects. All three rotations improved the simple structure in the person space to approximately the same degree. The unrotated solution identified 16 students (24%) with a single component (criteria: magnitude of largest factor score must be more than twice the magnitude of the next largest factor score). After the rotations 37 students (55%) were uniquely identified following the quartimax, 36 students (54%) after the varimax, and 38 students (57%) after the equamax. Thus the improvement toward simple structure was more than doubled resulting in slightly more than half the students being identified with a single component.

The second criterion is related to the change in the shape of the component curves as a result of a rotation of axes. The following results deserve mention. After rotation the first component curve no longer approximates the trial means. The shapes of each of the three

FIGURE 8

QUARTIMAX ROTATION APPLIED IN PERSON SPACE

AND INVERSE IN TRIAL SPACE

MEAN CROSS PRODUCT SOLUTION

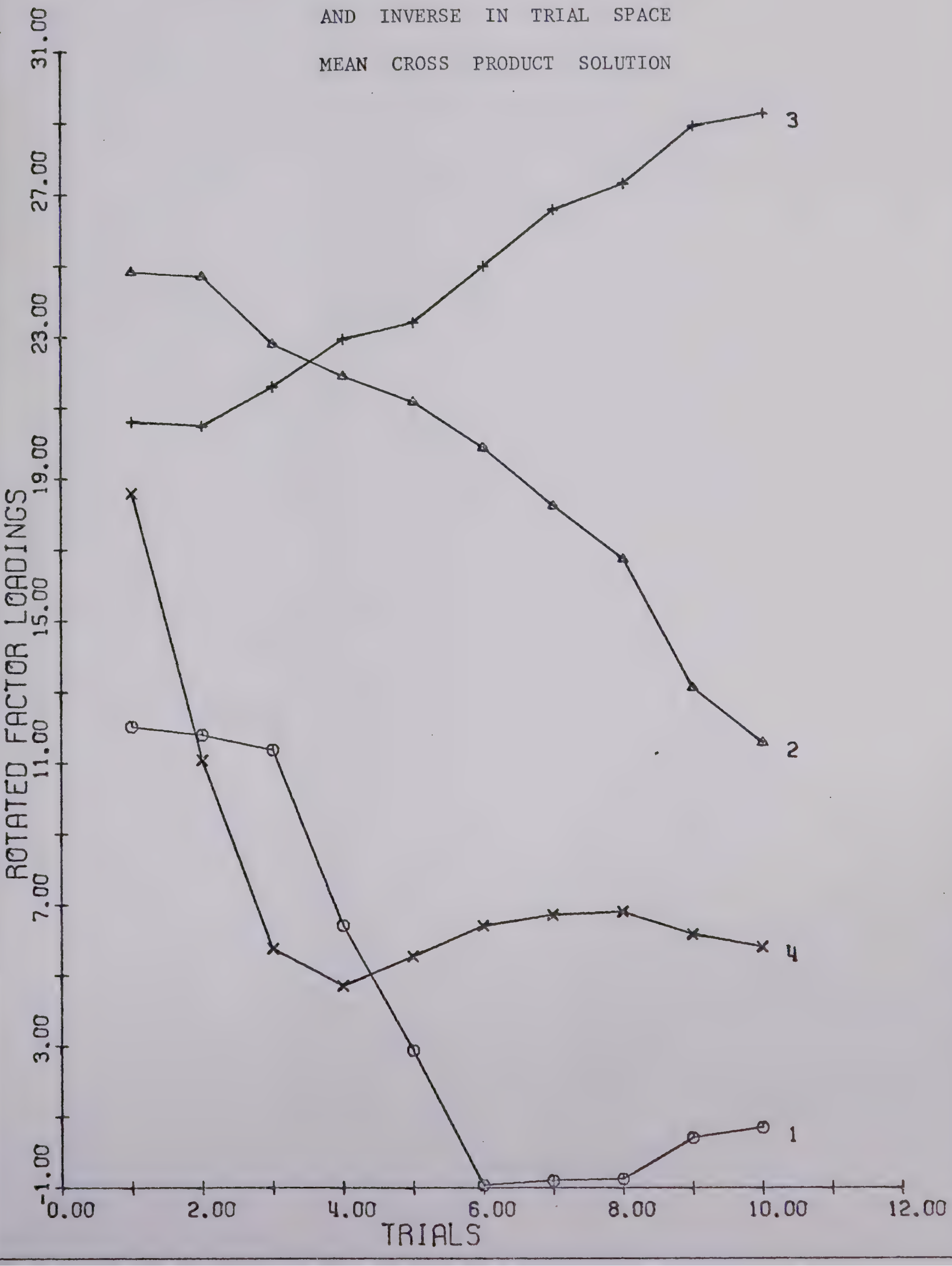


FIGURE 9

VARIMAX ROTATION APPLIED IN PERSON SPACE

AND INVERSE IN TRIAL SPACE

MEAN CROSS PRODUCT SOLUTION

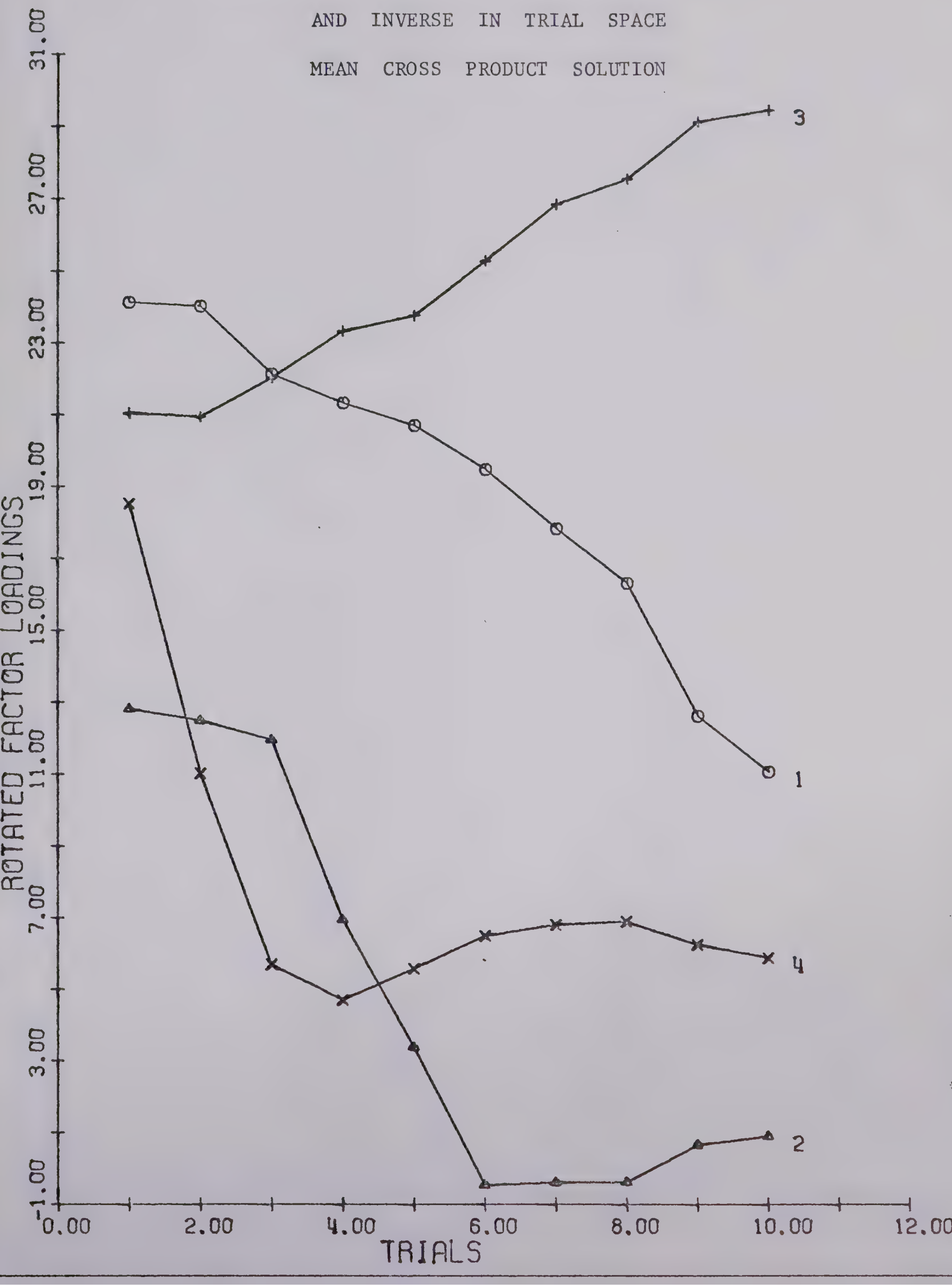
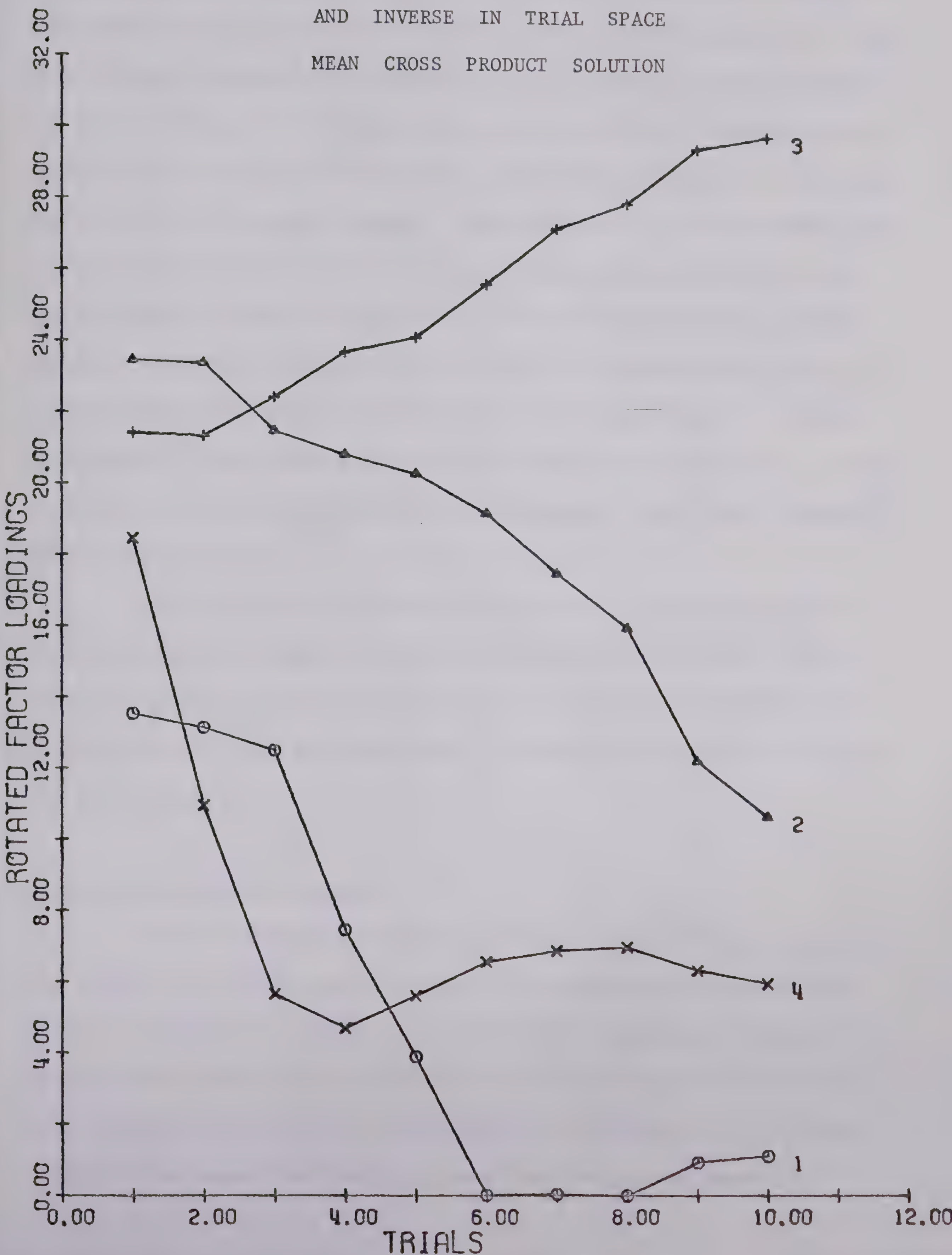


FIGURE 10

EQUAMAX ROTATION APPLIED IN PERSON SPACE

AND INVERSE IN TRIAL SPACE

MEAN CROSS PRODUCT SOLUTION



rotated sets of curves have virtually no similarity to the shapes of the unrotated curves (Figure 7). The three sets of rotated curves, each set considered as a collection, have almost identically the same shape. However although component curves three and four retain the same shape after all three rotations, the first component curve after the varimax rotation in the person space has the same shape as the second component curve after the quartimax or equamax rotation. Similarly, the second curve after the varimax rotation has the same shape as the first curve after the quartimax or equamax rotation. Generally, the rotated curves have a greater range of values than the unrotated curves. The rotated curves remain relatively smooth and remain representative of a typical type of student performance. Thus students that can be uniquely identified with a rotated component curve tend to have an actual performance curve that is similar to the rotated curve.

In conclusion, the orthomax rotations in the person space increase the extent to which students can be uniquely identified with a single component curve while maintaining the general meaningfulness associated with the shapes of the curves. All three rotations give virtually the same results.

Data Matrix Minus Trial Means

As mentioned in the earlier section, Issue on Choice of Matrix, the analysis of the data matrix with the trial means removed (i.e. the variance - covariance matrix) may be considered appropriate when the learning task remains the same and means are not an important parameter over the sequence of trials. The assumption of identical trials is warranted to the extent that one may assume that the general simulation

situation provides the major impact of the learning task, outweighing the influence of the cumulative specific values of the variables at a particular trial.

The relative value of applying Tucker's component curve method to the variance - covariance matrix was evaluated by comparing the results of this analysis with those from the mean cross product solution. The same criteria used for evaluation of the rotated solution remain valid, namely the meaningfulness of the shape of the component curves and the ability to associate each student with a unique component curve. An additional criterion, the degree of relationship with an external set of measures, will be examined in a later section after the nature of the external measures has been described in greater detail.

Since the trial means have been removed from the data matrix, this analysis focuses on relationships among deviation scores. Table IX gives the mean square ratios for the component curves that are extracted to account for the matrix of deviation scores. A comparison of these values with those of the F-distribution suggest that 4 components be retained. This is the same number that were obtained when the mean cross product matrix provided the initial data base.

The loadings of the component curves for each of the 10 trials are given in Table X and are presented pictorially in Figure 11. A review of the unweighted characteristic vectors indicates very close agreement in the shapes of the curves from the variance - covariance matrix with those from the mean cross product matrix, although vectors two and four were reflected. Since the pattern of eigenvalues is different from the two solutions, the resulting pictures of the factor loadings obscures this similarity to some extent.

TABLE IX

COMPONENT CURVE ANALYSIS OF VARIANCE - COVARIANCE MATRIX

MEAN SQUARE RATIOS

Component	Eigenvalue	df1	df2	Mean Square Ratio
1	2766.11	76	594	40.75
2	348.81	74	520	13.48
3	79.40	72	448	4.83
4	49.80	70	378	5.11
5	22.78	68	310	3.49
6	12.69	66	244	2.74
7	8.08	64	180	2.52
8	5.60	62	118	3.10
9	2.07	60	58	1.46
10	1.36	58	0	0

TABLE X

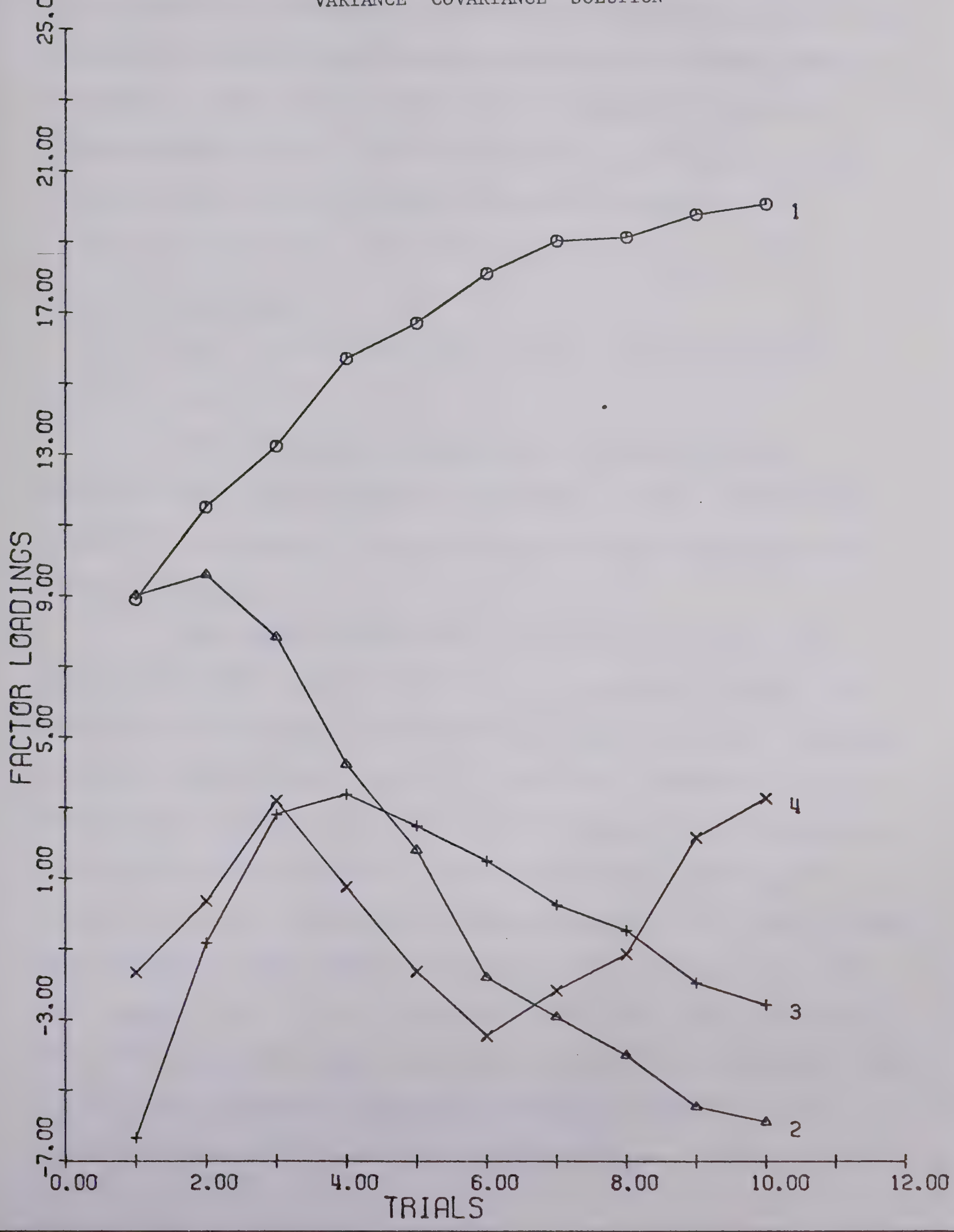
COMPONENT CURVE ANALYSIS OF VARIANCE - COVARIANCE MATRIX
LOADINGS OF TRIALS ON COMPONENT CURVES
(B_k^* MATRIX)

Trial	Component Curves 1	2	3	4
1	8.90	9.02	-6.34	-1.66
2	11.52	9.61	-0.82	0.36
3	13.24	7.84	2.82	3.21
4	15.71	4.23	3.39	0.77
5	16.71	1.82	2.50	-1.62
6	18.11	-1.80	1.51	-3.45
7	19.04	-2.92	0.26	-2.17
8	19.15	-4.01	-0.46	-1.14
9	19.80	-5.46	-1.94	2.17
10	20.10	-5.89	-2.56	3.28

FIGURE 11

UNROTATED COMPONENT CURVES

VARIANCE COVARIANCE SOLUTION



As before, factor scores were computed for each person on each component. Since the component curve solution provides an estimate for the deviation scores, it is possible to form a residual matrix of the difference between the actual deviation score and the estimate based on k components. For example, subject 1 had a value of 19.9 on trial 1. The mean value for trial 1 was 36.46 resulting in a deviation score of -16.56 for this subject. Using the component curve model

$$\hat{X}_{ji} = b_{j1} Y_{1i} + b_{j2} Y_{2i} + \dots + b_{jk} Y_{ki},$$

we obtain the estimate

$$\hat{X}_{11} = (8.90)(-.942)+(9.02)(-.715)+(-6.34)(-.020)+(-1.66)(.039)$$
$$= -14.76.$$

However the principle advantage of using the variance - covariance matrix must be evaluated using other criteria - the "meaningfulness" of the component curves and their usefulness in examining individual differences.

Any interpretation of the shapes of the component curves should make explicit mention of the fact that the curves represent patterns of deviation scores. Thus the first component no longer represents an average learning curve. Instead it represents a dimension of maximum variability - subjects with a high score on component one are those whose performance showed increasing deviation from the mean performance for the group. For example, subject 56 has factor scores of 1.617, -0.187, -0.599, and 0.450 for the four respective components. The ten deviation scores were computed: 2.8, 8.5, 13.1, 15.2, 16.6, 18.3, 18.2, 17.8, 17.8, 17.7. Each of the succeeding curves represents other patterns of deviation scores - for example component 2 represents a decreasing deviation from the mean, ie. a gravitation toward the average performance. However since

the curve has negative loadings on the last 5 trials, this implies that this type of performance would represent continuing performance away from the mean, in a negative direction. Subject 65 has factor scores of -0.617, 2.417, 0.366, and 0.896. His deviation scores were 14.8, 11.7, 14.7, 2.5, 0.4, -20.8, -22.4, -23.6, -24.1, and -23.9, verifying this interpretation.

Looking at the ability to discriminate individual differences, the unrotated factor score matrix was examined for simple structure. Recall that 16 subjects (24%) were uniquely identified with one component from the unrotated mean cross product matrix. Using the same criterion, the unrotated variance - covariance matrix distinguished 18 such subjects (27%). There is no apparent improvement in simple structure. However this will be investigated further by examining the results of various rotations.

The three rotations quartimax, varimax, and equamax were applied to the factor score matrix. The component curves corresponding to these rotations are given in Figures 12 - 14. The results were very similar to thos obtained when these rotations were applied to the mean cross product solution - the improvement toward simple structure in the person space was more than doubled. Once again there appears to be no major difference between the results of the three rotations.

Data Matrix Minus Person Means

Since the subjects have different entering behaviors, and to the extent they exhibit a degree of consistency of performance over the task, where the n + 1 trial may depend on the n th trial, it may be considered desirable to remove a portion of this effect from the performance

FIGURE 12

QUARTIMAX ROTATION APPLIED IN PERSON SPACE

AND INVERSE IN TRIAL SPACE

VARIANCE COVARIANCE SOLUTION

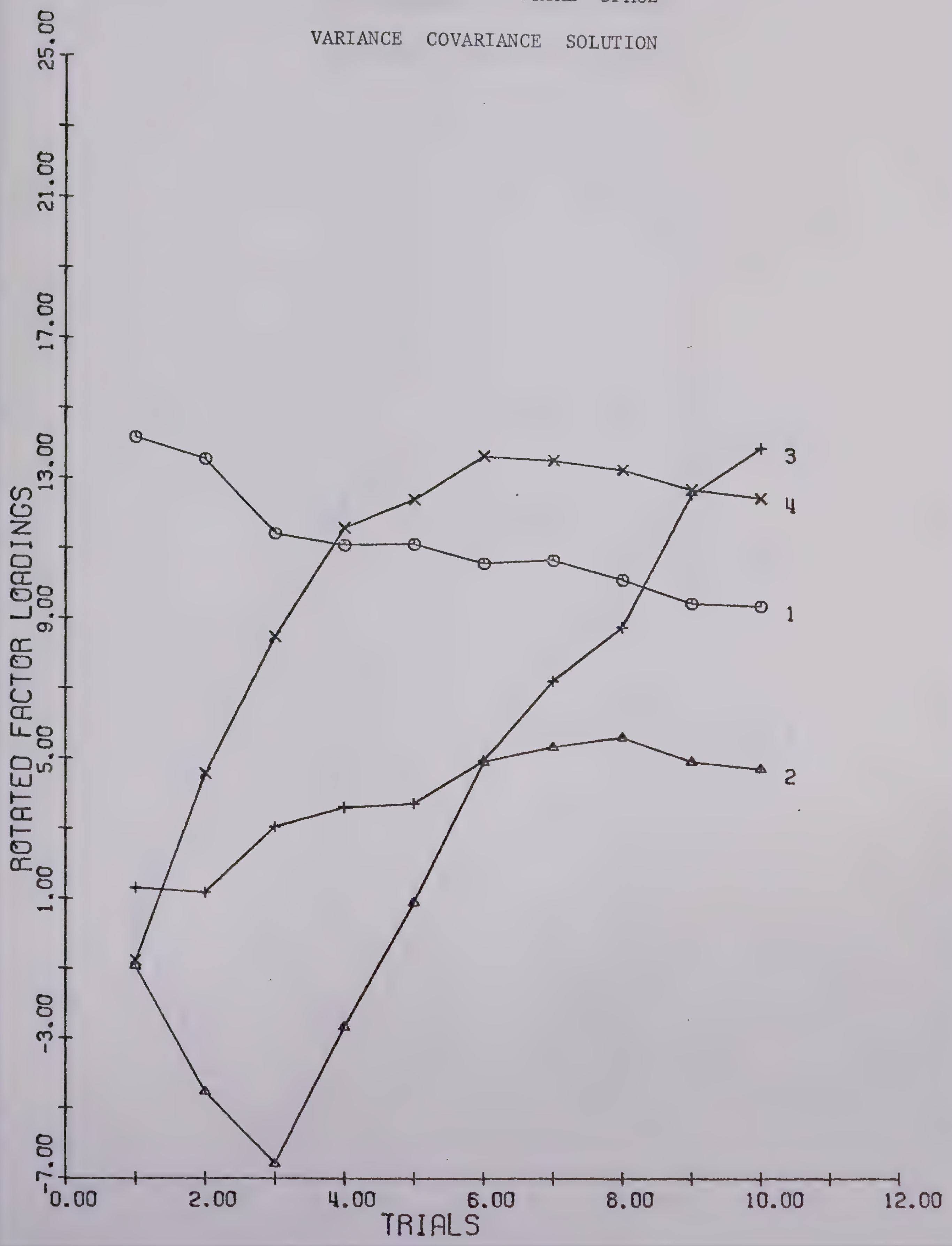


FIGURE 13

VARIMAX ROTATION APPLIED IN PERSON SPACE

AND INVERSE IN TRIAL SPACE

VARIANCE COVARIANCE SOLUTION

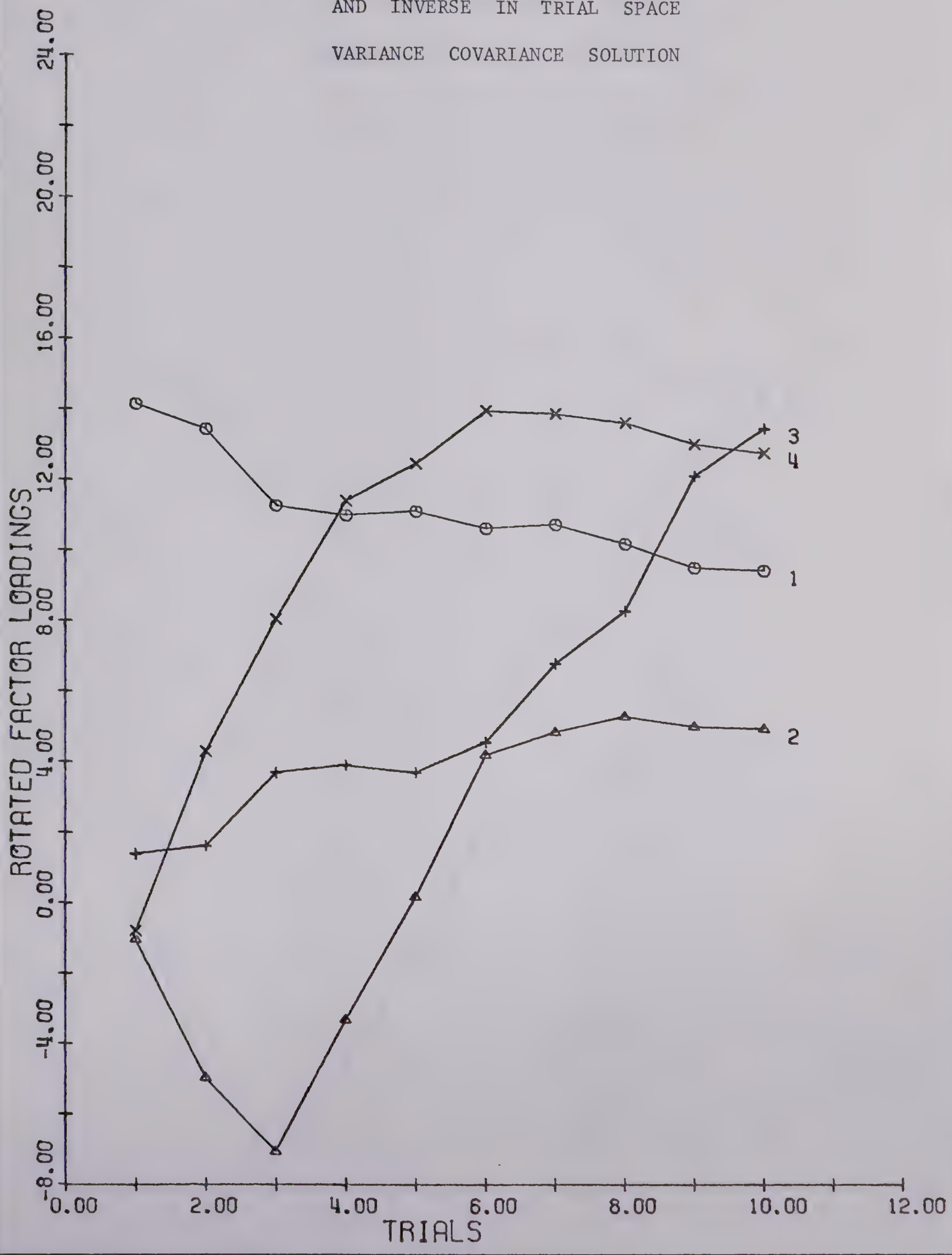
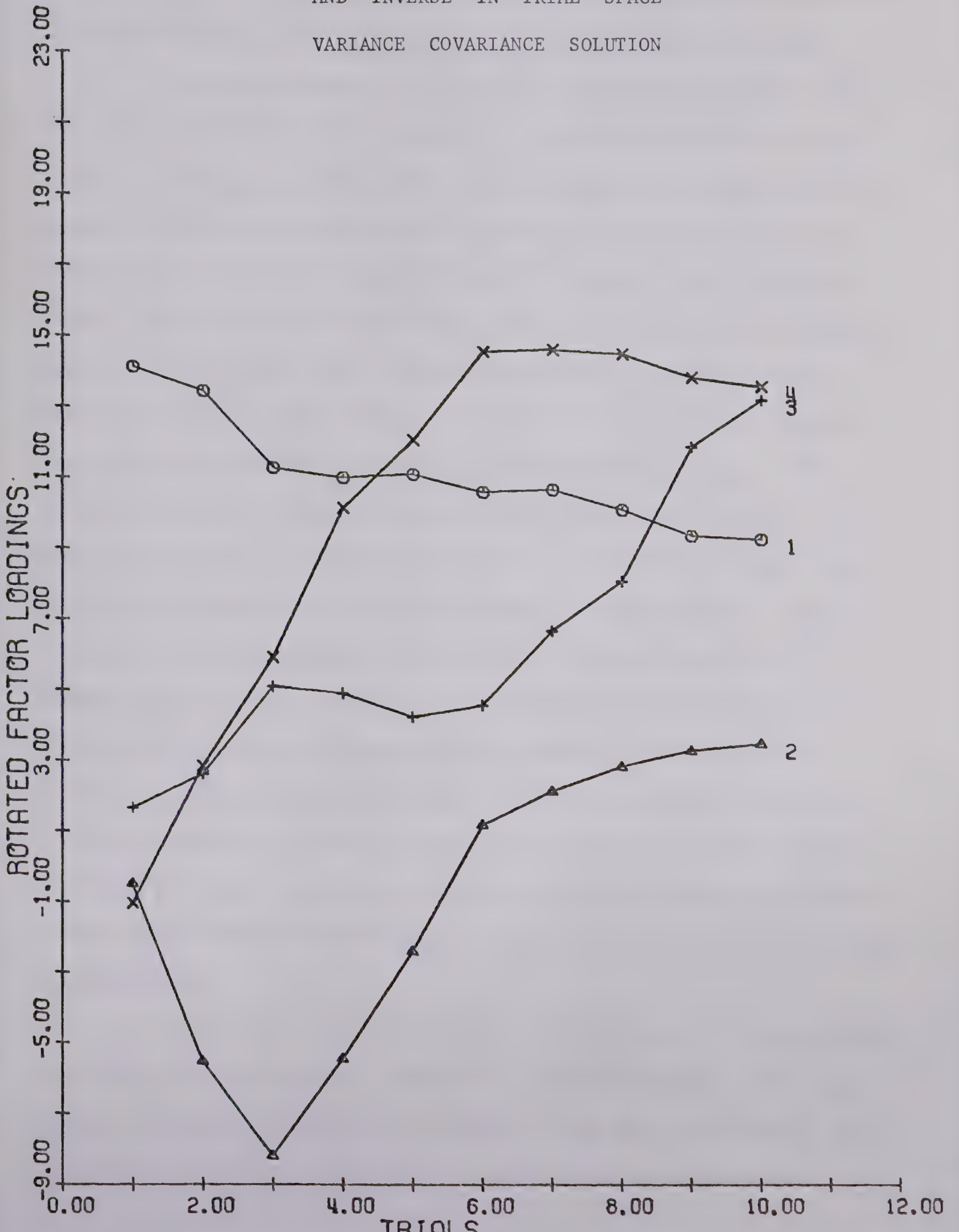


FIGURE 14

EQUAMAX ROTATION APPLIED IN PERSON SPACE

AND INVERSE IN TRIAL SPACE

VARIANCE COVARIANCE SOLUTION



data by subtracting the individual subject means from each person's performance scores. Following this rationale, Tucker's component curve analysis was applied to the data matrix with the person means removed.

The mean square ratios (Table XI) again indicate that four components be retained. The loadings of the component curves for each of the 10 trials are given in Table XII and Figure 15. A review of the shapes of these curves must take the nature of the analyzed data into consideration. The sharp negative slope of component curve one represents a type of performance that begins with values well above a subject's individual average but which decreases over the ten values to a point well below the individual average. The curve is not a direct measure of how well the subject has performed on the simulation exercise, rather it is a measure of how well the subject has performed when compared to his individual average. For example, subjects 9 and 16 both had high scores on the first component yet a review of Table 5 reveals subject 9 had an average score of 383 whereas subject 16 had an average score of 76. The second component curve indicates a performance that starts below person's average score, increases sharply over the next two trials to a value above the subject's personal average, followed by a gradual decrease in performance scores to a level slightly below the average score. Curves three and four have a much more noticeable oscillation about the subject's average performance and do not appear representative of a strong "learning" interpretation.

A review of the factor scores on the unrotated curves permitted identification of 12 subjects (18%) with a unique component. This represents a slight decrease from the 16 subjects that were equivalently identified when the unrotated mean cross product solution was examined.

TABLE XI

COMPONENT CURVE ANALYSIS OF DATA WITH PERSON MEANS REMOVED

MEAN SQUARE RATIOS

Component	Eigenvalue	df1	df2	Mean Square Ratio
1	574.98	76	594	22.23
2	96.00	75	520	6.36
3	52.40	72	448	6.07
4	22.93	70	378	4.02
5	13.34	68	310	3.48
6	8.30	66	244	3.34
7	5.64	64	180	4.48
8	2.10	62	118	2.79
9	1.42	60	58	77.06
10	0.02	58	0	0

TABLE XII

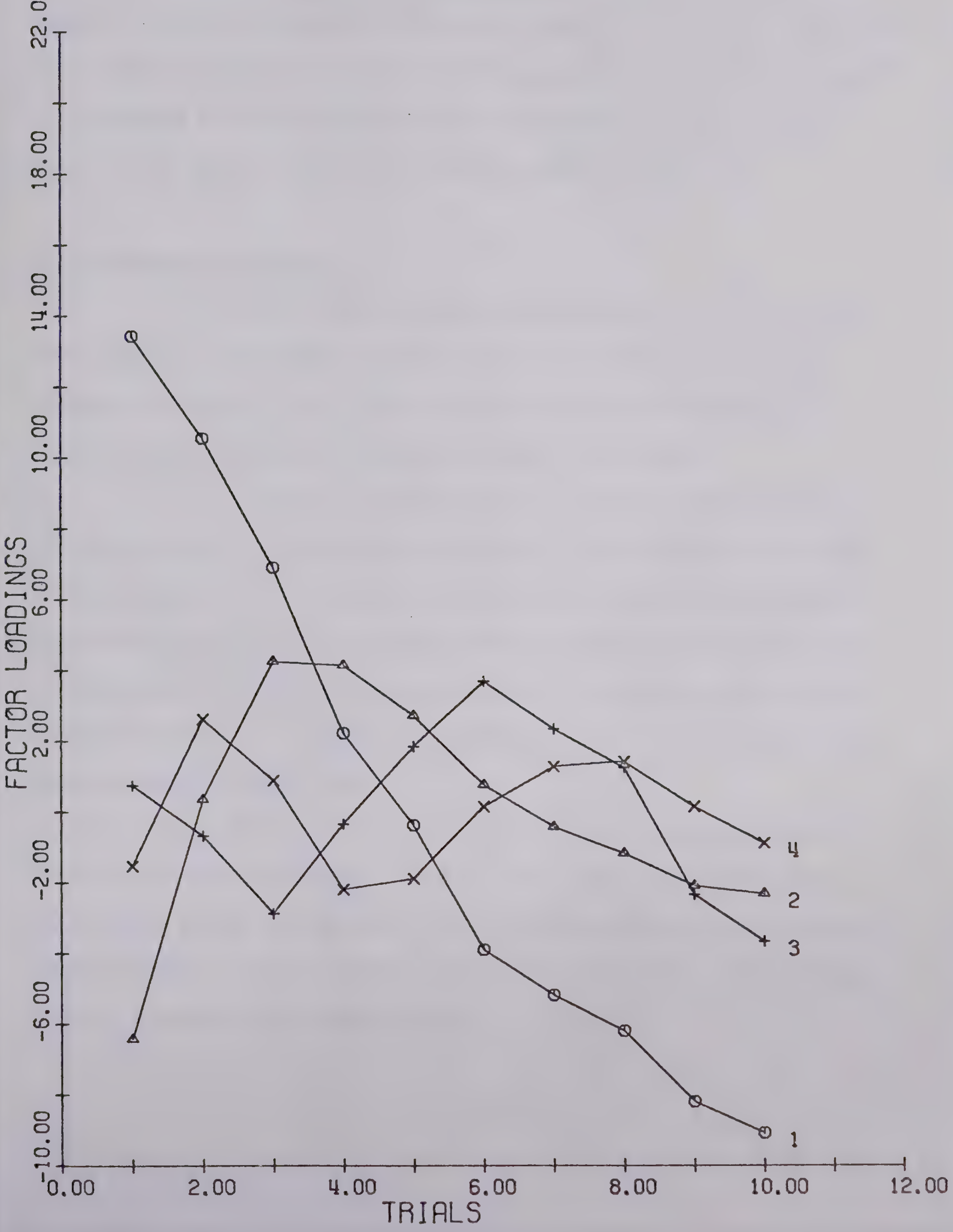
COMPONENT CURVE ANALYSIS OF DATA WITH
PERSON MEANS REMOVED
LOADINGS OF TRIALS ON COMPONENT CURVES
(B_k^* MATRIX)

Trial	Component Curve 1	2	3	4
1	13.44	-6.41	0.76	-1.53
2	10.56	0.36	-0.66	2.63
3	6.92	4.27	-2.87	0.90
4	2.24	4.16	-0.34	-2.19
5	- 0.37	2.73	1.85	-1.89
6	- 3.89	0.77	3.70	0.15
7	- 5.18	-0.42	2.35	1.28
8	- 6.19	-1.18	1.25	1.42
9	- 8.19	-2.08	-2.33	0.15
10	- 9.08	-2.31	-3.66	-0.88

FIGURE 15

UNROTATED COMPONENT CURVES

DATA WITH PERSON MEANS REMOVED



Quartimax, varimax, and equamax rotations were applied to the factor score matrix. Only the quartimax results are given (Figure 16) since all three rotations yielded similar results. Thirty-three subjects (49%) were uniquely identifiable after the quartimax rotation was carried out, compared with 55% after the same rotation was carried out on the factor score matrix from the mean cross product solution.

Double Centered Data Matrix

The previous two sections explained the rationale for removing either the trial means or the person means. Thus it is logically defensible to consider the effect of removing both sets of means - resulting in an analysis of the double centered data matrix.

The results of removing the trial means from the data with the person means already removed was similar to the results of removing the trial means from the raw data matrix. In both cases the removal of the trial means did not materially affect the nature of the solution. The component curves resulting from an analysis of the double centered matrix are given in Figure 17 and are very similar to the curves obtained in the previous section (Figure 15).

The efficacy of the solutions resulting from an analysis of the four types of data matrix (raw data, data minus trial means, data minus person means, and the double centered data matrix) will be investigated in greater detail when the relationship with a set of external measures is considered in a later section.

FIGURE 16

QUARTIMAX ROTATION APPLIED IN PERSON SPACE
AND INVERSE IN TRIAL SPACE
DATA WITH PERSON MEANS REMOVED

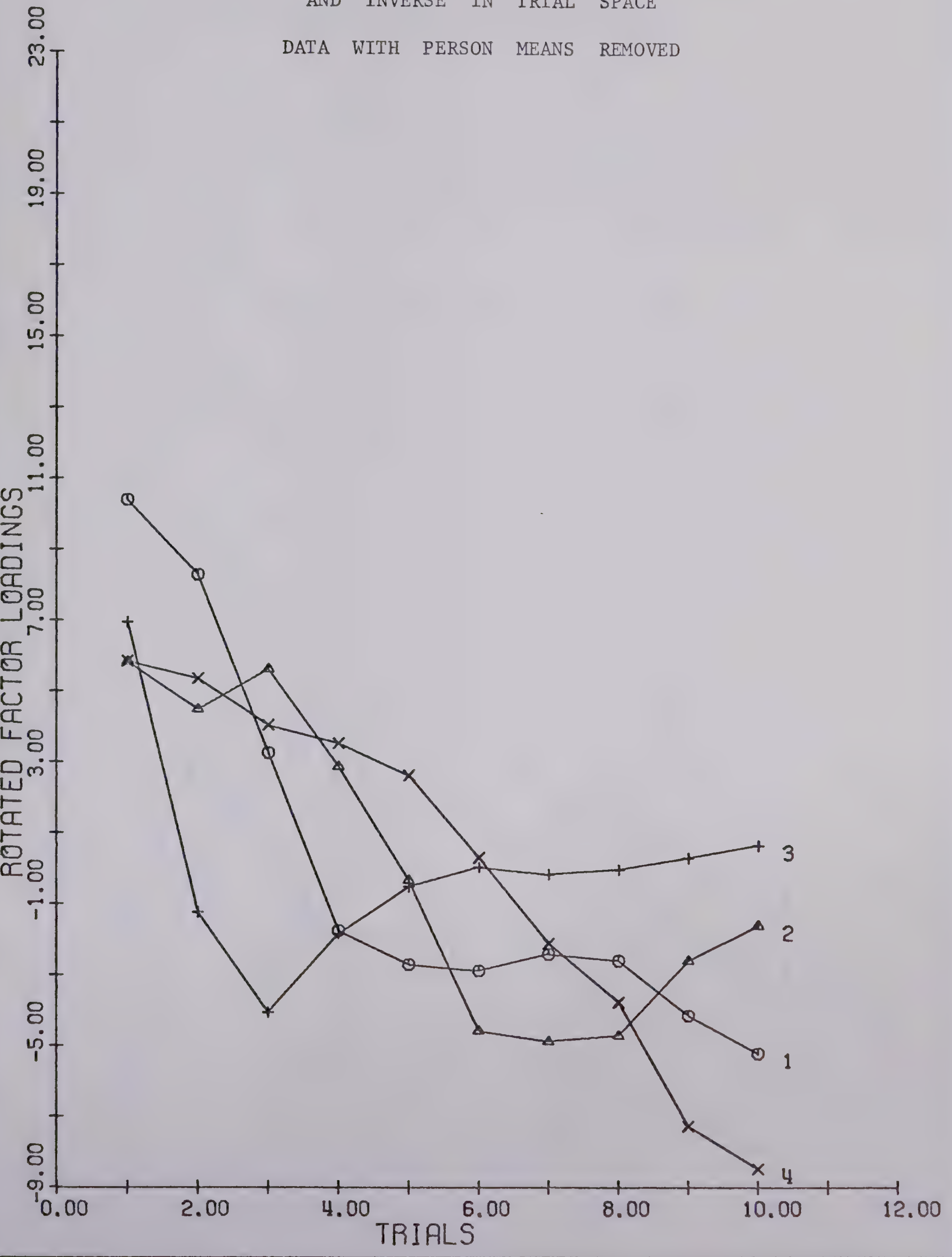
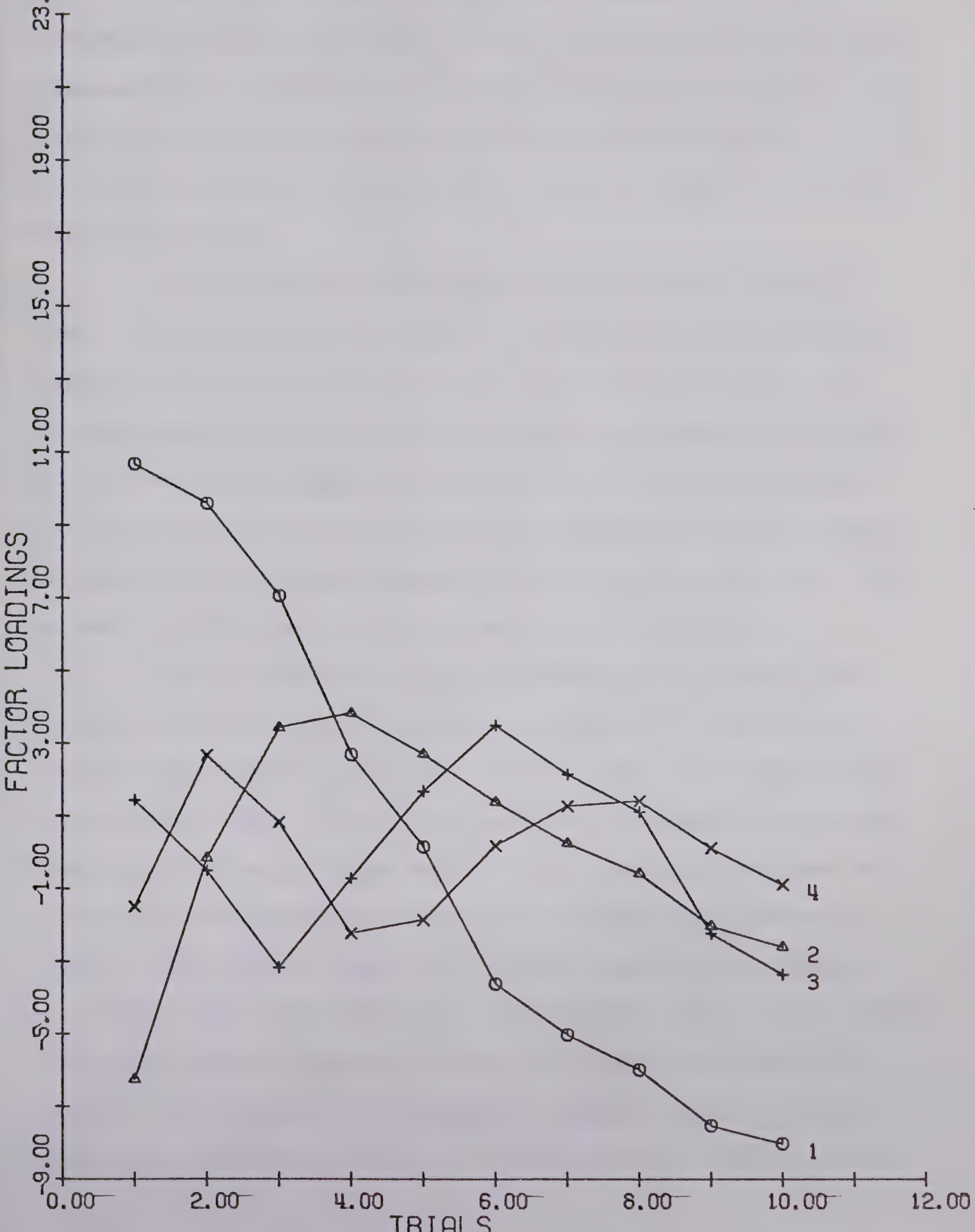


FIGURE 17

UNROTATED COMPONENT CURVES

DOUBLE CENTERED DATA MATRIX



II. COMPONENT CURVE ANALYSIS OF SIMULATED RANDOM PERFORMANCE

There were two principle reasons for conducting a computer simulation of student performance. First, by randomly varying the inputs corresponding to the decision points in the simulation game FISHY, it was possible to actually test the game model before it was programmed for the IBM 1500 Instructional System and before the first students were used for further pre-testing.

The simulation of student decisions was repeated a number of times. The results of each run provided a basis for modifying both the initialization and the equations of the fishing model such that; (a) the magnitude of all results (both intermediate and final) was less than 32,767, a constraint imposed by the limits of the IBM 1500 system, and (b) the final results were similar to those considered desirable assuming the student had made random decisions, namely that the value of the "cash on hand" variable showed a slight decrease over the 10 trials.

The second reason for conducting Monte Carlo studies on student performance data was to investigate the nature of the results of a component curve analysis on this type of data. This latter objective was achieved in two steps. First, a data matrix was generated without consideration of the simulation game model. Thus a matrix with 100 rows and 10 columns (corresponding to 100 people and 10 trials) was generated using the IBM subroutine RANDU (1968), so that each entry was obtained in a random manner from a rectangular distribution. The mean square ratios (Table XIII) clearly indicate that only one component curve should be retained. A review of the trial loadings indicated this curve is very close to the trial means. It may be inferred that the existence of more

TABLE XIII

COMPONENT CURVE ANALYSIS OF MATRIX OF
RANDOM NUMBERS
MEAN SQUARE RATIOS

Component	Eigenvalue	df1	df2	Mean Square Ratio
1	23.80	109	891	30.04
2	1.00	107	784	1.34
3	.96	105	679	1.38
4	.92	103	576	1.42
5	.75	101	475	1.24
6	.68	99	376	1.20
7	.62	97	279	1.15
8	.60	95	184	1.22
9	.50	93	91	1.10
10	.45	91	0	0

than one component curve indicates the existence of something other than random data. It should also be noted that this does not imply that all non-random data will result in more than one component curve being identified.

The second step in the investigation of component curve analysis involved imbedding the random number generation within the context of the fishing game model. The procedure involved generating a random number for each possible decision that could be made by a student at each trial. The only limitation imposed on the random values was that they remain within the range of admissible values. For example, the procedure did not permit the catching of more fish than there were available. This was identical to the procedure used for originally testing the fishing game model except; (1) the final game model to be used in the study was specified at this stage, and (2) the results of the random performance were subjected to Tucker's component curve analysis. As before, a 100 x 10 matrix of outcome values was generated. The mean square ratios (Table XIV) indicate the retention of three component curves with the possible inclusion of the fourth component curve. The trial loadings (Table XV) are illustrated in Figure 18.

The following points deserve mention. First, more than one component curve was required to account for the random performance. The structure of the game model appears to impose some structure on the results of the component curve analysis. Second, the shapes of the component curves resulting from the analysis of random performance are very similar to those obtained from the actual student performance data (Figure 7). Two possible inferences may be made. The students, as a group, did not perform in a significantly different manner from a

TABLE XIV

COMPONENT CURVE ANALYSIS OF MATRIX OF
RANDOM PERFORMANCE
MEAN SQUARE RATIOS

Component	Eigenvalue	df1	df2	Mean Square Ratio
1	101.78	109	891	41.20
2	18.75	107	784	95.54
3	1.02	105	679	15.97
4	.19	103	576	4.54
5	.10	101	475	3.76
6	.04	99	376	1.73
7	.04	97	279	1.92
8	.02	95	184	1.56
9	.02	93	91	1.15
10	.01	91	0	0

TABLE XV

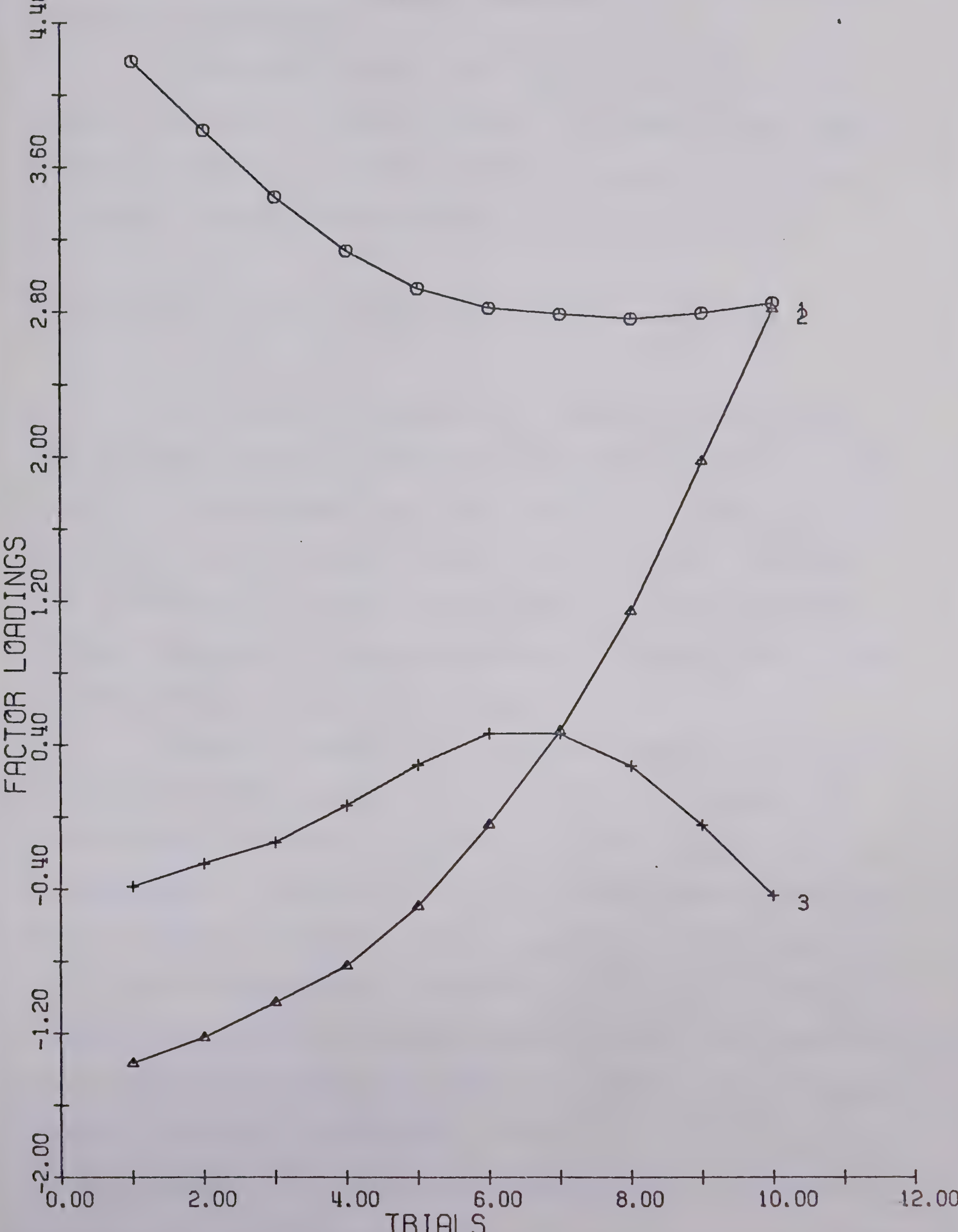
COMPONENT CURVE ANALYSIS OF MATRIX
OF RANDOM PERFORMANCE
LOADINGS OF TRIALS ON COMPONENT CURVES
(B_k^* MATRIX)

Trial	Component Curve 1	2	3	4
1	4.19	-1.36	-0.38	-0.15
2	3.81	-1.22	-0.26	-0.06
3	3.44	-1.03	-0.14	0.06
4	3.14	-0.83	0.06	0.16
5	2.93	-0.49	0.29	0.19
6	2.83	-0.04	0.46	0.08
7	2.79	0.48	0.46	-0.08
8	2.77	1.14	0.28	-0.22
9	2.80	1.98	-0.04	-0.08
10	2.86	2.82	-0.44	0.16

FIGURE 18

UNROTATED COMPONENT CURVES

RANDOM PERFORMANCE



simulated set of random performance data. Alternatively, it may be true that component curve analysis tends to give similarly shaped curves under a variety of performances.

These results emphasize the importance of having a set of measures, independent of the data analyzed via component curve analysis, that can be related to the results of Tucker's analysis. One such set of external measures will be considered in the next section.

III. FACTOR ANALYSIS OF MARKER TESTS FOR COGNITIVE FACTORS

Two measures of "impulsivity - reflectivity" (mean latency time and number of errors) obtained from the computer-based MFF test were added to the ten recognized marker tests from the Kit of Reference Tests for Cognitive Factors (French, Ekstrom, and Price, 1967). These tests were hypothesized to represent a 6-factor space. A maximum likelihood procedure developed by Joreskog and described by Harman (p. 219) was used to obtain estimates of the factor loadings.

Maximum likelihood factor analysis is based on the assumption that the variables have a multivariate normal distribution. All twelve variables were tested for goodness of fit (χ^2 statistic) to a normal distribution. The two measures from the MFF test did not satisfy the normality criteria. Therefore, using a suggestion provided by Winer (p. 218), these two variables were transformed to a new scale which better satisfies the assumptions underlying maximum likelihood factor analysis. Thus a natural logarithmic transformation was applied to the mean latency time and a square root transformation was used on the number of errors. The final results of the normality goodness-of-fit test are presented in

Table XVI.

Maximum likelihood estimates of the factor loadings are determined as the solution to two matrix equations. These equations cannot be solved algebraically, instead an iterative procedure must be used. Joreskog's (1967) computational method ensures the convergence of the iterative procedure. The method involves the removal, if necessary, of the variables that prevent convergence (this is called the improper, or Heywood case), obtaining a proper solution for the remaining variables, and then combining the previously removed variables with the proper solution to obtain a final combined solution. If the unique variance of a variable approaches zero (i.e. the variable lies entirely in the common factor space), as the solution approaches convergence then it is possible to consider that variable as a factor. The variable (factor) is removed, the partial correlations are computed and the attempt at a proper converged solution is repeated with the remaining variables. If such a Heywood case has arisen, the improper solution refers to the estimates of the factor loadings at the point where the 'special' variables have zero unique variance (ie. before convergence has been attained). The corresponding proper solution refers to the loadings upon convergence of the maximum likelihood solution after these variables have been removed. A final combined solution is obtained by incorporating the previously removed variables into the proper solution. The inclusion of a variable (factor) to the proper solution involves the addition of one row and one column to the factor loading matrix. Since the removed variable may be considered an orthogonal factor, the entries for the new row are all zero except for a one where the row intersects with the corresponding new column. The column entries consist of the original correlations of the

TABLE XVI

MARKER TESTS FOR STUDENTS' CHARACTERISTICS
GOODNESS OF FIT TEST TO NORMAL DISTRIBUTION

Variable (Marker Test)	df	χ^2	P
1 - Letter Sets (I-1)	6	16.68	.01
2 - Figure Classification (I-3)	6	14.26	.03
3 - Object - Number (M_a-2)	7	12.19	.09
4 - First and Last Names (Ma-3)	7	3.22	.86
5 - Addition Test (N-1)	6	12.23	.06
6 - Subtraction and Multiplication (N-3)	5	5.58	.35
7 - Mathematics Aptitude (R-1)	5	13.84	.02
8 - Necessary Arithmetic Operations (R-4)	5	4.50	.48
9 - Vocabulary Test (V-1)	5	4.69	.45
10 - Vocabulary Test (V-2)	5	14.74	.01
11 - MFF - No. of Errors	5	31.81	.00
12 - MFF - Mean Latency Time	7	20.08	.00
11' -MFF - Square Root (No. of Errors)	7	16.113	.02
12' -MFF - Log_e (Mean Latency Time)	6	8.80	.19

retained variables with this new factor. This process is repeated until the complete set of variables is included in the final solution. A detailed explanation of the procedure may be found in an article by Joreskog (1967). The maximum likelihood approach includes a test for goodness of fit that was initially developed by Lawley (Joreskog, 1967). This test may be used to determine the appropriate number of common factors. The procedure is outlined by Harman (p. 220).

Analysis of the marker test scores revealed an improper solution. The goodness of fit test indicated 5 factors should be retained. The initial improper solution using all twelve variables is given in Table XVII. Since variables 3, 6, 7, and 9 had no remaining unique variance, the previously mentioned adjustment was made. The final unrotated solution is presented in Table XVIII.

The selection of a criterion for rotation was based on the following considerations. First, improvement toward simple structure was desirable to permit an easier identification and interpretation of the obtained factors. Second, since the initial battery of marker tests were designed to identify independent factors, an orthogonal rotation was considered necessary. The possibilities were thus reduced to the family of orthomax rotations. Since each factor was based on an equal number of marker tests, it was desirable to distribute the variance equally over all five factors. Therefore an equamax rotation was selected as the final step prior to identification of the factors. The results of this rotation are provided in Table XIX.

An examination of these loadings permits the following interpretation for each factor:

TABLE XVII

MAXIMUM LIKELIHOOD FACTOR ANALYSIS OF MARKER TESTS

IMPROPER SOLUTION

Marker Test	I	II	III	IV	V	h_j^2
1 (I-1) Induction	.502	.087	-.149	-.107	-.267	.365
2 (I-3) Induction	.285	.144	-.363	.104	.025	.245
3 (Ma-2) Memory	.606	-.194	.729	.207	-.010	.979
4 (Ma-3) Memory	.552	.151	.395	.090	-.077	.498
5 (N-1) Number Facility	.655	-.471	-.133	-.268	.020	.741
6 (N-3) Number Facility	.622	-.630	-.235	-.376	-.001	.980
7 (R-1) Gen.Reasoning	.733	.136	-.451	.469	.024	.980
8 (R-4) Gen.Reasoning	.648	.212	-.133	.130	-.003	.499
9 (V-1) Verbal Comp.	.584	.696	.081	-.383	.029	.980
10 (V-2) Verbal Comp.	.387	.509	-.044	-.266	-.119	.496
11' Sq.Rt (MFF Error)	-.237	-.270	.203	.053	.769	.764
12' LN (MFF Latency)	.312	.202	-.125	.168	-.546	.480
Σa^2	3.422	1.628	1.201	0.772	0.983	

TABLE XVIII

MAXIMUM LIKELIHOOD FACTOR ANALYSIS OF MARKER TESTS

FINAL UNROTATED SOLUTION

Marker Test	I	II	III	IV	V	h_j^2
1 (I-1) Induction	-.489	.083	.147	-.112	-.287	.363
2 (I-3) Induction	-.281	.137	.367	.095	.010	.242
3 (Ma-2) Memory	-.624	-.188	-.729	.211	.000	1.000
4 (Ma-3) Memory	-.554	.155	-.380	.092	-.080	.490
5 (N-1) Number Facility	-.648	-.460	.133	-.280	.014	.728
6 (N-3) Number Facility	-.620	-.631	.233	-.403	.000	.999
7 (R-1) Gen.Reasoning	-.736	.127	.477	.464	.000	1.000
8 (R-4) Gen.Reasoning	-.643	.206	.144	.124	-.034	.493
9 (V-1) Verbal Comp.	-.582	.714	-.070	-.384	.000	1.001
10 (V-2) Verbal Comp.	-.376	.504	.048	-.260	-.153	.489
11' Sq.Rt.(MFF Error)	.218	-.245	-.191	.052	.766	.733
12' Ln (MFF Latency)	-.298	.182	.121	.167	-.575	.495
$\sum a^2$	3.390	1.610	1.211	0.792	1.031	

TABLE XIX

MAXIMUM LIKELIHOOD FACTOR ANALYSIS OF MARKER TESTS
FACTOR LOADINGS AFTER EQUAMAX ROTATION

Marker Test	I	II	III	IV	V	h_j^2
1 (I-1) Induction	.137	.271	.301	.216	-.365	.363
2 (I-3) Induction	-.087	.140	.100	.440	-.105	.242
3 (Ma-2) Memory	.981	-.025	.184	-.054	.033	1.021
4 (Ma-3) Memory	.629	.257	.066	.103	-.117	.490
5 (N-1) Number Facility	.199	.050	.813	.156	-.018	.728
6 (N-3) Number Facility	.075	-.019	.992	.099	-.014	1.000
7 (R-1) Gen.Reasoning	.214	.079	.192	.930	-.217	1.000
8 (R-4) Gen.Reasoning	.296	.302	.185	.501	-.171	.493
9 (V-1) Verbal Comp.	.234	.951	.031	.162	-.116	1.000
10 (V-2) Verbal Comp.	.079	.638	.021	.128	-.241	.488
11' Sq.Rt.(MFF Error)	.031	-.219	-.034	-.067	.824	.734
12' Ln (MFF Latency)	.139	.093	-.008	.217	-.648	.495
Σa^2	1.644	1.628	1.858	1.519	1.406	

Factor I - Associative (Rote) Memory

Factor II - Verbal Comprehension

Factor III - Number Facility

Factor IV - General Reasoning

Factor V - Impulsivity

The first four factors coincide with those provided in the Manual for Kit of Reference Tests for Cognitive Factors (French, Ekstrom, and Price, 1963). Factor V - Impulsivity - is based on the high positive loading for the variable "square root of the number of errors on the MFF test" and the high negative loading for the variable "natural logarithm of the average response latency time". These factors will be utilized in the last phase of this study which will examine relationships between these characteristics of the subjects and their performance on the simulation game as described by the component curves.

Before these relationships can be investigated it is necessary to compute the factor scores for each subject on each of the five identified factors. Harris (1967) has reviewed four methods of computing such factor scores. Harris adopts the conventional definition of "true" factor scores as direction cosines locating the common factors in the person space. One of the methods reviewed is Bartlett's estimate of the factor scores. The matrix equation for this method is

$$\hat{F} = Z\, U^{-2} A\, (A'\, U^{-2} A)^{-1}$$

where Z is the N- by -n matrix of standard scores

U^2 is the m- by -m diagonal matrix of unique variances

A is the n- by -m matrix of factor pattern coefficients

$\hat{F}$ is the N- by -m matrix of estimated factor scores.

This estimate is univocal, that is, the correlation matrix between F and

the "true" factor scores is the identity matrix. Anderson and Rubin (Harris, 1967, p. 372) have developed a method that insures that $\hat{F}'\hat{F} = I$, but for an orthogonal rotation (for example, equamax) these two methods provide proportional factor scores.

Bartlett's method was used to obtain the factor scores for the students on the five equamax rotated cognitive factors thereby maintaining the univocal nature of the results (Table XX). The intercorrelation matrix $\hat{F}'\hat{F}$ given in Table XXI provides a good approximation to the identity matrix indicating the essential orthogonal nature of the factor scores.

The last two sections have reported the results of the students' performance (via component curve analysis) on a simulation game and their scores on an independent set of measures (via factor analysis) related to cognitive abilities. The following section will examine the relationships between these two sets of data.

IV. RELATIONSHIP BETWEEN COMPONENT CURVES AND EXTERNAL MEASURES OF SUBJECTS' CHARACTERISTICS

Canonical Correlation Approach

Canonical correlation methods involve determining a set of weights for two sets of variables such that the multiple correlation between the two weighted sets is a maximum. If one of the sets contains a single variable the method becomes one of multiple regression (as used in the next section). Several sets of weights are frequently possible, subject to the restriction that they be independent of other sets of weights. Bartlett (Cooley and Lohnes, p. 37) has developed a chi-square test for

TABLE XX

MAXIMUM LIKELIHOOD FACTOR ANALYSIS OF MARKER TESTS

FACTOR SCORES ON ROTATED (EQUAMAX) FACTORS

Subject ID.	FACTOR I	II	III	IV	V
1	-1.198	-0.057	1.160	1.286	0.208
2	-0.329	0.691	-0.462	3.637	0.220
3	-0.482	0.034	-0.084	-0.204	-0.022
4	-0.346	-0.944	-1.640	0.306	0.570
5	0.312	-0.630	-0.505	-0.706	-1.995
6	-0.753	0.111	-0.842	-0.683	-0.808
7	-1.301	-0.365	-0.244	0.687	1.616
8	0.128	0.045	-0.134	-0.612	2.053
9	-0.068	1.272	-1.419	-1.251	-1.573
10	-0.453	0.697	1.675	-1.289	0.412
11	-1.293	-1.425	-0.297	0.984	1.378
12	-1.596	-0.284	0.026	-0.961	2.133
13	-0.778	-0.060	0.673	-1.015	-0.982
14	0.507	1.352	1.752	0.108	-1.029
16	-1.848	-0.844	1.402	-1.472	0.706
17	-0.432	0.378	2.840	3.348	0.607
18	-0.105	-0.686	-0.748	-0.778	-0.784
19	0.388	-0.578	0.714	0.620	-0.582
20	0.963	-0.030	-0.811	-0.458	1.823
21	-1.294	-0.198	-0.084	-0.570	-1.390
24	-0.063	-0.312	-0.468	0.970	-0.474
25	-0.833	0.461	-1.553	-0.249	-1.702
26	-0.283	1.421	-0.630	-0.252	2.163
27	-0.700	-1.253	-1.214	-0.198	-0.591
28	1.417	-0.255	0.315	0.183	-0.589
31	0.631	-0.796	1.025	-1.194	-0.312
32	1.764	-0.800	-0.874	-0.280	-1.303
33	1.618	-0.612	0.150	-0.333	1.478
34	-0.425	0.448	-0.932	0.106	-0.324
35	2.278	1.689	0.097	-0.886	-0.546
36	-1.254	-1.407	0.807	-0.696	-0.448
37	-0.726	0.079	-0.005	-0.273	-1.556
38	-0.034	-0.484	0.962	-0.659	0.294
39	-0.022	1.462	-0.676	0.448	-0.027
40	-0.552	-1.410	0.333	0.601	-0.047

TABLE XX (Continued)

Subject ID.	FACTOR I	II	III	IV	V
41	2.063	-2.099	-0.105	-0.813	0.169
42	-0.517	0.938	0.349	0.107	-0.174
43	1.158	-0.891	-1.633	0.809	2.062
45	-0.451	0.658	-0.630	1.190	0.957
46	-1.391	0.586	1.070	-0.585	-0.235
47	1.548	1.142	-0.754	1.570	0.717
48	-1.073	-0.958	-1.679	-0.183	0.971
49	1.371	-1.110	0.717	-0.874	0.315
51	0.425	-0.663	-0.345	-0.038	-1.065
52	1.476	0.029	-0.847	0.003	-0.048
53	0.698	2.289	-0.780	-0.564	-1.277
54	-0.688	-0.852	0.078	-0.312	0.227
55	-0.860	-0.361	0.868	0.727	-1.131
56	1.637	-1.610	-0.231	2.024	-2.135
57	-0.266	0.234	0.619	0.751	-0.443
58	0.112	-0.755	1.014	0.237	0.976
59	-1.538	0.764	0.493	0.259	0.614
60	0.748	2.890	1.226	-0.449	-0.913
61	-0.703	-0.225	-1.098	0.534	0.846
62	-0.264	0.958	-0.548	1.400	-0.606
63	1.379	-0.320	2.243	-0.249	1.387
64	-0.011	1.274	-1.476	-1.037	1.524
65	-0.390	-0.738	0.158	-0.838	-1.628
66	0.076	-0.746	-0.449	0.386	-1.888
67	1.798	-0.024	1.450	-0.802	0.998
68	0.865	-0.265	0.776	0.784	1.857
69	1.443	0.271	-0.725	0.535	1.307
70	-0.285	-0.154	-0.725	-1.460	-0.410
72	-0.659	0.884	-0.458	0.172	0.317
73	-0.221	2.339	0.873	-0.557	0.410
74	-0.554	0.898	-1.221	1.738	-0.050
75	0.237	-1.092	1.457	-0.350	-2.234

the null hypothesis that the two sets of variables are unrelated.

A canonical correlation analysis was carried out for the scores on the unrotated component curves from the cross-product solution and the factor scores on the set of 5 cognitive factors. The input correlation matrix is presented in Table XXI and the results are given in Table XXII. The maximum canonical correlation was 0.57 which is significant at the 0.05 level. There was only one set of weights that yielded a significant canonical correlation.

The weighting system indicates that component curve I is the most important component in the sense of being maximally related to the set of cognitive factor scores. Similarly, the most important cognitive factors are impulsivity, general reasoning, and number facility.

The canonical analysis was repreated for the various rotated solutions (Table XXIII). The results of these additional analyses may be summarized as follows: (1) the canonical correlation for the various rotated solutions does not change as would be expected since these solutions are all transformations of one another, (2) the weights for the cognitive factors remain constant, (3) the interchange of the weights between curves I and II when changing from a quartimax to a varimax rotation in the person space agrees with the interchange of shapes of these two component curves as seen in Figures 8 and 9. The canonical weighting system is primarily dependent upon the shape of the curves, and (4) with the exception of the previous point, there is no appreciable difference in the weights among the three rotated solutions, just as there is no appreciable difference among the shapes of the curves from the three solutions.

A comparison of the results of the canonical correlation between the unrotated curves (Figure 7) and the curves after the quartimax

TABLE XXI

CORRELATION MATRIX OF SCORES ON FOUR UNROTATED COMPONENT CURVES WITH SCORES ON FIVE COGNITIVE FACTORS

	Component Curves				Cognitive Factors				
	I	II	III	IV	1	2	3	4	5
I	1.000								
II	.533	1.000							
III	.258	-.044	1.000						
IV	-.085	.015	.007	1.000					
1	-.237	-.103	-.121	-.018	1.000				
2	-.110	-.086	.026	-.071	-.003	1.000			
3	-.170	-.038	.088	-.258	-.003	-.001	1.000		
4	.203	.238	-.112	-.081	-.001	.010	.004	1.000	
5	-.347	-.307	-.021	-.005	.005	.018	-.003	.059	1.000

TABLE XXII

RESULTS OF CANONICAL CORRELATION OF FOUR COMPONENT CURVES WITH FIVE COGNITIVE FACTORS

Component Curves			Cognitive Factors	
I	.899	1.	Assoc. Memory	-.345
II	.187	2.	Verbal Comp.	-.238
III	-.299	3.	Number Facil.	-.442
IV	.262	4.	Gen.Reasoning	.455
		5.	Impulsivity	-.650

$R_c = 0.57$, $\chi^2_{20} = 33.51$, $p < 0.05$

TABLE XXIII

RESULTS OF CANONICAL CORRELATION OF FOUR ROTATED COMPONENT CURVES WITH FIVE COGNITIVE FACTORS

a) QUARTIMAX IN PERSON SPACE

Component Curves		Cognitive Factors	
I	-.053	1. Assoc. Memory	-.345
II	.504	2. Verbal Comp.	-.238
III	.765	3. Number Facil.	-.442
IV	.398	4. Gen.Reasoning	.454
		5. Impulsivity	-.650

$R_c = 0.57$, $\chi^2_{20} = 33.51$, $p < 0.05$

b) VARIMAX IN PERSON SPACE

Component Curves		Cognitive Factors	
I	.500	1. Assoc. Memory	-.345
II	-.036	2. Verbal	-.238
III	.767	3. Number Facil.	-.442
IV	.401	4. Gen.Reasoning	.454
		5. Impulsivity	-.650

$R_c = 0.57$, $\chi^2_{20} = 33.51$, $p < 0.05$

c) EQUAMAX IN PERSON SPACE

Component Curves		Cognitive Factors	
I	-.020	1. Assoc. Memory	-.345
II	.497	2. Verbal	-.238
III	.769	3. Number Facil.	-.442
IV	.403	4. Gen.Reasoning	.454
		5. Impulsivity	-.650

$R_c = 0.57$, $\chi^2_{20} = 33.51$, $p < 0.05$

rotation in the person space (Figure 8) indicates the general spread of importance (in the sense of higher weights) following the rotation. Thus component curve I (unrotated) had a weight of .899 followed by curve III (-.299) whereas curve III (rotated) had a weight of .765, curve II (.504), and curve IV (.398).

Canonical correlations were also computed for the other three types of component curve solution. These results can be summarized briefly. The removal of the trial means had virtually no effect on either the canonical correlation or the weighting system. Once again, this is in agreement with the minor change in the shapes of the curves. The removal of the person means reduced the canonical correlation to a level of statistical non-significance, therefore no weights are reported. Similar results were noted for the double-centered matrix.

In addition to revealing the relationships between the component curve solution and a set of ability measures, canonical correlation may be used to evaluate the relative efficiency of the solution as compared with the original raw data. Data reduction was achieved in two ways: the ten trials were reduced to four component curves and the twelve marker tests were reduced to five cognitive factors. Referring to Table XXIV, comparison of the results of a canonical correlation analysis of both sets of raw data with both sets of reduced data reveals that a total data reduction of 59% results in a loss in percent of variance accounted for of 30%. This implies that combined use of component curve analysis and factor analysis resulted in a descriptive system approximately twice as efficient as one using the actual raw data.

The relationship between the cognitive factors and the scores on the component curves will be investigated in greater detail in the following

TABLE XXIV

COMPARISON OF EFFICIENCY OF
DATA REDUCTION METHODS

	Method	max. R_c	% variance accounted for	Total no. of scores	% of original Total
1.	Raw performance scores + marker test scores	.79	62	1474	100
2.	Raw performance scores + cog.factor scores	.70	49	1005	68
3.	Comp. curve scores + marker test scores	.64	41	1072	73
4.	Comp. curve scores + cog.factor scores	.57	32	603	41

section, where the cognitive factor scores will be compared with the individual component curves, rather than with the set of curves as was done in this section.

Multiple Linear Regression Approach

The purpose of the multiple regression method is to derive weights $\beta_1, \beta_2, \cdots \beta_5$ for the predictor variables (factor scores on the cognitive factors) $X_1, X_2, \cdots X_5$, and an additive constant β_o such that the resulting weighted composite variable Y, defined by

$$Y = \beta_o + \beta_1 X_1 + \cdots \beta_5 X_5$$

predicts a criterion variable, Y with a minimum sum of squared error.

The present situation has one notable feature - the predictor variables are all independent of one another. This results in a considerable simplication of the usual formulae; for example, it now follows that

$$\beta_j = r_{YX_j} \frac{S_Y}{Sx_j}$$

and $R^2 = r^2_{YX_1} = r^2_{YX_2} + \cdots + r^2_{YX_5}$.

Darlington (1968) discusses three principle measures of the "importance" of a predictor variable: (1) the squared validity, $r^2_{YS_j}$; (2) the standardized beta weight, β'_j ; (3) the usefulness of X_j, defined as the amount R^2 would drop if X_j were removed from the regression equation; and points out that these are all equivalent in the special case of uncorrelated predictor variables. However the sign of the beta weight provides additional information - it indicates the direction of the relationship and may thus be used to help identify the nature of the criterion variable with respect to the nature of the predictor variable.

Draper and Smith (p. 171) describe a stepwise regression procedure which gives the values of the F-statistic for testing the contribution of each predictor variable to the existing regression equation. A computer program (MULR06: Div. of Educational Research Services, U. of Alberta) based on this procedure was used to perform the necessary regression analyses.

The factor scores on a particular component curve were taken as the criterion variable and the factor scores on the five cognitive factors were used as the predictor variables. Thus for a specified component curve solution, say the unrotated cross-product solution, a total of four regression equations were derived, one for each component curve.

Table XXV gives the standardized beta weights for all significant ($\alpha = 0.10$) predictors for the unrotated component curves. The magnitude of these beta weights provide a measure of the importance of the various predictors. It is informative to refer to the shapes of the respective curves (Figure 7) when describing the relationship between the component curves and their predictors.

Consider the unrotated cross-product solution. Component I represents fairly constant performance over the 10 trials of the simulation game. Three factors; associative (rote) memory, general reasoning, and impulsivity are related to scores on this component. Students who have high scores on memory and general reasoning and a low score on impulsivity tend to have higher scores on this component curve. For example; subject 56 had a high loading on component I (See Table VIII) his standardized scores on the three cognitive factors were: associative (rote) memory, 1.637; general reasoning, 2.024, and impulsivity, -2.135. For component II, which shows a strong improvement in performance, the

TABLE XXV

STANDARDIZED BETA WEIGHTS FOR SIGNIFICANT[1] PREDICTORS OF FACTOR SCORES ON UNROTATED COMPONENT CURVES

PREDICTORS	CROSS-PRODUCT SOLUTION Component I	II	III	IV
1. Assoc.Memory	.23	-	-	-
2. Verbal Comp.	-	-	-	-
3. Number Facility	-	-	-	-.26
4. Gen.Reasoning	.22	.26	-	-
5. Impulsivity	-.36	-.32	-	-
% Variance Accounted for	22.6	16.0	-	6.7

1. Level of significance = 0.10

memory factor is no longer associated with performance. The general reasoning factor shows a slightly stronger relationship with scores on this component and impulsivity shows a slightly weaker relationship. Subject 16 provides a good illustration of this situation. This subject had a high negative score on component II, therefore one would expect this person to have a low score on general reasoning and a high score on impulsivity. The standardized factor scores are -1.472 and 0.706 respectively. These statements are illustrated in Figure 19 which gives selected learning curves for four students, including subjects 56 and 16 mentioned above.

Another interesting feature is brought out by noting the negative relationship between number facility and component IV. At first glance this is a disturbing finding - why should an ability such as number facility hinder performance? However it is an easy manner to reflect this component, thereby bringing the results into agreement with intuition. Therefore the set of beta weights may not only be used to help identify components but may also be used to guide one particular type of rotation, reflection (a rotation of 180°).

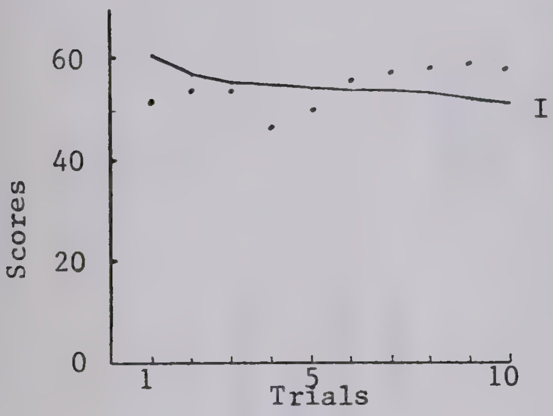
It was mentioned in the previous section, Mean Cross Product Matrix - Orthogonal Rotations, that different rotations may result in similar shaped component curves. For example, component I following a quartimax rotation in the person space (Figure 8) has virtually an identical shape to component II after a varimax rotation in the person space (Figure 9). The standardized beta weights in Table XXVI are almost the same for these two components.

The regression analyses revealed a lack of improvement in prediction among the different rotated solutions. In fact there was a slight

FIGURE 19

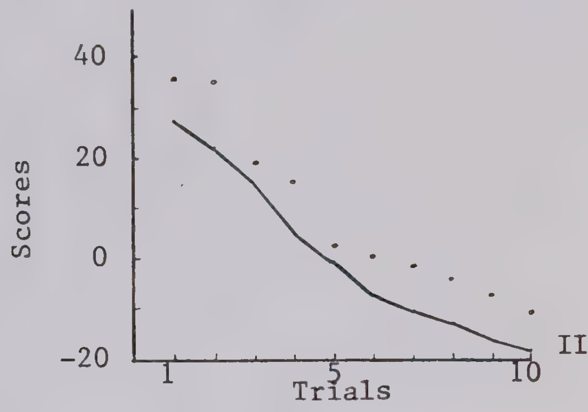
SELECTED INDIVIDUAL LEARNING CURVES

(The dots represent actual performance scores x 10^{-1})



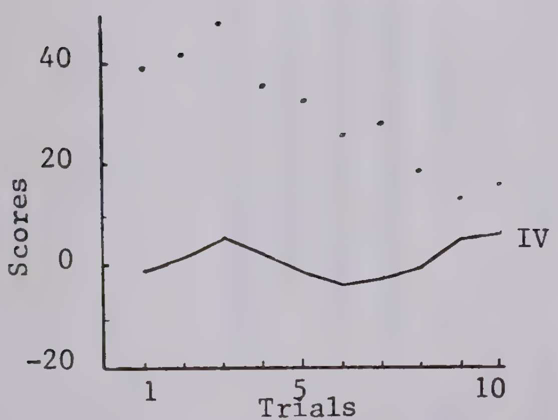
Subject 56

Scores on Comp. Curves		Scores on Cog. Factors	
I.	1.658	Ma.	1.637
II.	.771	R.	2.024
III.	-.320	I.	-2.134
IV.	-.591	N.	-.231



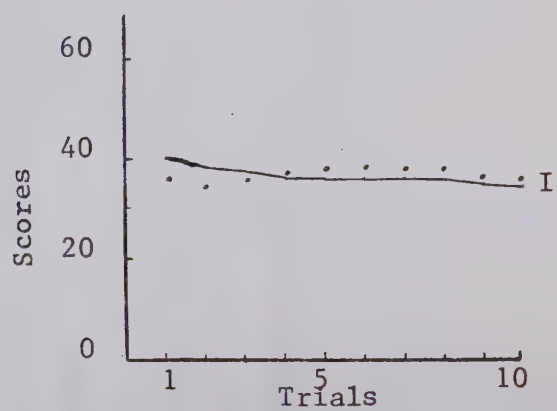
Subject 16

Scores on Comp. Curves		Scores on Cog. Factors	
I.	.256	Ma.	-1.848
II.	-2.137	R.	-1.472
III.	-.113	I.	.706
IV.	.002	N.	1.402



Subject 67

Scores on Comp. Curves		Scores on Cog. Factors	
I.	.426	Ma.	1.798
II.	-.476	R.	-.802
III.	-.337	I.	.998
IV.	-1.255	N.	1.450



Subject 24

Scores on Comp. Curves		Scores on Cog. Factors	
I.	1.097	Ma.	-.063
II.	.333	R.	.970
III.	.254	I.	-.474
IV.	.215	N.	-.468

TABLE XXVI

STANDARDIZED BETA WEIGHTS FOR SIGNIFICANT[1] PREDICTORS OF FACTOR SCORES ON ROTATED COMPONENT CURVES - PERSON SPACE ROTATIONS FOR CROSS-PRODUCT SOLUTIONS

PREDICTORS	QUARTIMAX Component				VARIMAX Component				EQUAMAX Component			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1. Assoc. Memory	-	-	-	-	-	-	-	-	-	-	-	-
2. Verbal Comp.	-	-	-	-	-	-	-	-	-	-	-	-
3. Number Facility	.22	-	-	-	-	.21	-	-	.21	-	-	-
4. Gen.Reasoning	-	-	.29	-	-	-	.29	-	-	-	.29	-
5. Impulsivity	-	-	-.35	-	-	-	-.35	-	-	-	-.35	-
% Variance Accounted for	4.7	-	19.5	-	-	4.5	19.5	-	4.4	-	19.5	-

1. Level of significance = 0.10

decrease in the amount of predictability (% of variance accounted for) for the rotated solutions. Thus it appears that the transformations result in more extreme shapes for the component curves - curves which in turn bear less relationship to a set of measures on cognitive abilities.

The next chapter will summarize the results obtained from the component curve analyses of the student performance data on the simulation game, the maximum likelihood factor analysis of the marker tests for the cognitive factors, the canonical correlation between the two resulting sets of data, and the multiple linear regression of the cognitive factor scores on the component curve scores. Conclusions based on these results will be stated and suggestions for further research will be presented.

V. SUBJECTS' REACTION TO THE STUDY

The Final step in the collection of data required the students to indicate their position on a 7-point scale (1 = dislike, 7 = like) for the following two statements:

1. Indicate on the scale your feelings about taking part of your school curriculum on a computer terminal.
2. Indicate on the scale your feelings about the game FISHY.

The mean scale values were 6.8 and 6.2 respectively for these two statements. These two questions were asked approximately one week after their participation on the computer terminals. It seems therefore that the students had a generally favorable attitude about both computer-assisted instruction and the type of simulation game represented by FISHY.

Approximately two-thirds of the subjects felt the set of

cognitive tests were either too hard or too long. The complete set of tests took approximately 2 hours and 20 minutes to complete. The recommended minimum grade level for these tests was either grade 6 or grade 8.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

I. SUMMARY

The primary purpose of this study was to evaluate Tucker's component curve analysis as a method for describing student performance on a computer-based simulation game. The study focused on the characteristics of the component curves resulting from variations in applying the method of component curve analysis to the student performance data.

The data base for the study consisted of a random sample of 67 grade eight students from one junior high school in Edmonton, Alberta. The students were introduced to the computer instructional system and then they proceeded through ten cycles of a simulation game on the salmon fishing industry. The scores for each student consisted of the value of the "cash on hand" variable at the end of each cycle. After the students had completed the simulation exercise they received a computer based version of the Matching Familiar Figures test. This test provided a measure on an impulsive-reflective dimension. The following week a set of 10 marker tests from the Kit of Reference Tests for Cognitive Factors (French, Ekstrom, and Price, 1967) were administered to the students.

The data collected by the above procedure was then subjected to the following analyses. First, a component curve analysis of the student performance data on the simulation game was performed. Four component curves were identified and factor scores on these four curves were computed. The shape of the curves represented typical performance,

in the sense that subjects with high scores on a particular component tended to have an actual performance curve with a shape similar to that of the curve in question. Using a criterion that the factor score with the largest magnitude must be at least double the magnitude of the next largest factor score, 24% of the subjects were uniquely identified with a single component curve. The solution was then subjected to three rotations in the person space: quartimax, varimax, and equamax. All three rotations gave virtually the same result. The percentage of students identifiable with a unique component increased to about 55% while the general shapes of the curves remained representative of typical student performance.

Second, a component curve analysis of the data with the trial means removed was performed. This procedure was considered appropriate to the extent that one could consider the simulation task as remaining the same over the series of trials. The results of this analysis were very similar to the previous results. The interpretation of the shapes of the component curves emphasized that the curves represented patterns of deviation scores.

Third, a component curve analysis of the data with the person means removed was carried out. This implied analyzing all subjects on the same base line - performance about their own means. The resulting curves did not permit as strong a learning interpretation as the other two solutions. The results of the three rotations in the person space increased the percentage of students identifiable with a unique curve to about 49%.

Combining the rationale of the previous two analyses, a component curve analysis of the double centered matrix was then conducted.

The results of this analysis were very similar to the results from the data with only the person means removed - the additional removal of the trial means did not noticeably modify the results.

Two additional component curve analyses were conducted on sets of random data. First, a matrix of random numbers was analyzed. The results clearly indicated that one component curve could describe the data satisfactorily. Second, random numbers were used to simulate student decisions at each decision point in the fishing game model. A component curve analysis of the resulting performance data indicated the retention of three component curves. The structure of the game model imposed some structure on the nature of the results of the component curve analysis. The shapes of these three curves were similar to those obtained from the original component curve analysis of the actual student performance data.

The next step consisted of performing a maximum likelihood factor analysis on the ten marker tests plus the two measures of impulsivity obtained from the Matching Familiar Figures test. Five factors were selected and subjected to an equamax rotation. The resulting five factors were identified as Associative (Rote) Memory, Verbal Comprehension, Number Facility, General Reasoning, and Impulsivity. Factor scores on these factors were computed for each student.

The relationship between this set of cognitive factor scores and the scores on the component curves was then examined by means of canonical correlation analyses. The largest weights were assigned to the first unrotated component curve and to the cognitive factors impulsivity, general reasoning, and number facility. When the method was applied to scores on the curves after the quartimax rotation, the system of weights was

more even for the component curves although the canonical correlation of 0.57 was not changed. A comparison of the proportion of data reduction (via component curve analysis and maximum likelihood factor analysis) versus a loss in canonical correlation indicated that a total data reduction of 59% resulted in a loss of percent of variance accounted for of 30%.

Finally, a more detailed analysis of the relationship between the cognitive factor scores and the scores on the component curves was conducted by means of multiple linear regression. Referring to the unrotated component curves, the scores on curve I were significantly related to the scores on associative (rote) memory, general reasoning, and impulsivity; curve II was related to general reasoning and impulsivity; and curve IV was related to number facility. After the quartimax rotation curve I was significantly related to number facility and curve III was related to general reasoning and impulsivity.

The next section presents the conclusions arising from this study.

II. CONCLUSIONS

In general, the results of this study have indicated the potential value of Tucker's component curve analysis for describing student performance on a complex simulation game. Since more than one component curve was required to account for the variation in the performance data, the method possesses the important advantage of explicitly delineating individual differences in performance when they do occur. This feature was shown to be related to individual differences in cognitive abilities.

The results of the study suggest the value of analyzing the mean cross product matrix in the component curve analysis. This procedure utilizes all of the available information in the analysis. The removal of the trial means did not appreciably alter the results. This may be explained by the similarity of the means over the 10 trials. The effect was primarily one of subtracting a constant from the data matrix, resulting in only a slight change in the nature of the results. In contrast to this, the removal of the person means had a noticeable effect on the results. But this resulted in the removal of the main source of correlation between scores on the component curves and scores on the cognitive factors. The results of a component curve analysis of the double centered matrix were similar to those resulting from the analysis of the data with the person means removed.

The three methods of rotation provided mixed results. All three rotations were essentially equivalent, therefore only the quartimax rotation in the person space will be mentioned. The principal advantage from the rotation was the approximate doubling of the number of subjects that could be uniquely identified with a single component. Although this rotation did not affect the canonical correlation with the scores on the cognitive factors, it did reduce the number of statistically significant relationships between the cognitive factors and the individual component curves, as examined by means of multiple linear regression.

An unexpected finding, but one that may have major implications, was noticed when the random performance data was analyzed by means of component curve analysis. Three component curves were required to account for the data instead of only one curve. The structure of the simulation game model had imposed a structure on the component curve solution. This

may thus provide a method for classifying such games.

This same analysis emphasized the importance of having a set of independent measures to provide additional information on the nature of the component curve solution. The shapes of the three component curves derived from the random performance were very similar to the shapes of the curves derived from the actual student performance. Thus an interpretation based on the relationship between the scores on the component curves and the scores on the cognitive factors was necessary to ensure their value.

The results of the canonical correlation analyses revealed two other points that deserve comment. First, the importance of the component curves as measured by the magnitude of the weights for the respective component curves did not agree with the importance of the curves as measured by their eigenvalues. For example, component II (unrotated) had a smaller weight than either curves III or IV (Table XXII). This may imply the omission of the some relevant factors, such as short term memory, from the set of external measures. Second, there was a net increase in efficiency resulting from the gain measured in terms of data reduction versus the loss in precision of the relation between the scores on the component curves and the scores on the cognitive factors.

The use of simulation games and models as an instructional technique is a new and expanding development in education today. Tucker's component curve analysis represents a method for describing student performance on such a learning situation. The technique has the potential to become an example of a statement by Gallagher (1964), "Nothing seems to direct the flow of research energies so much as a well-constructed measuring instrument".

III. RECOMMENDATIONS

This study has introduced a method for measuring student performance during their actual interaction with a game model. The study provided information on the nature of the solution obtained by a component curve analysis of performance data for one group of students over one presentation of the simulation game. This study could represent the first step in a possible program of research on simulation games.

Three recommendations for possible replication studies may be made. First, since the method relies on factor analytic techniques, the sample size should be increased. Second, if time permits, the number of cycles of the game should be increased to 20 or 30 trials. This would permit the study of component curves of greater length. Third, new variables should be considered for inclusion into the set of external measures. The importance of the impulsivity measure in the present study illustrated the value of including variables from outside the cognitive domain. For example, new technological developments may soon permit the use of eye-movement and pupil diameter data that will indicate what aspects of the feedback information the student is attending to while using a simulation game.

Another possible area of investigation would be the construction and testing of models of student decision-making behavior. The present study examined one such model, that of random performance. More complex models could contain well defined strategies, which in turn could be related to a set of hypothesized abilities or personality measures. The interaction of such decision making models with the simulation game model would generate a set of performance scores that could be analyzed

by means of component curve analysis. The suitability of such decision-making models would be determined by comparing the results from the simulated performance with the results from an analysis of actual student performance on the game.

The possibility of using component curve analysis to classify various simulation game models should be investigated in greater detail. The number and shape of component curves resulting from an analysis of random decision strategies may provide an index of complexity.

The main recommendation is related to a programmatic approach to research on simulation games. Principles of experimental design should be applied to studies involving repeated playings of the same game. Also the structural characteristics of the game model should be systematically varied and the resulting effect on performance should be studied. The method of component curve analysis represents one method that could be used to measure and evaluate the results of these studies.

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APPENDICES

APPENDIX A

SAMPLE PAGES FROM THE

KIT OF REFERENCE TESTS FOR COGNITIVE FACTORS

Name: ______________________________

LETTER SETS TEST — I-1

Each problem in this test has five groups of letters with four letters in each group. Four of the groups of letters are alike in some way. You are to find the rule that makes these four groups alike. The fifth group is different from them and will not fit this rule. Draw an X through the group of letters that is different.

NOTE: The rules will not be based on the sounds of groups of letters, the shapes of letters, or whether letter combinations form words or parts of words.

Examples:

A.	NOPQ	~~DEFL~~	ABCD	HIJK	UVWX
B.	NLIK	PLIK	QLIK	~~THIK~~	VLIK

In example A, four of the groups have letters in alphabetical order. An X has therefore been drawn through DEFL. In example B, four of the groups contain the letter L. Therefore, an X has been drawn through THIK.

Your score on this test will be the number of problems marked correctly minus a fraction of the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the letter groups.

You will be allowed 7 minutes for each of the two parts of this test. Each part has 1 page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Suggested by Letter Grouping by L. L. Thurstone

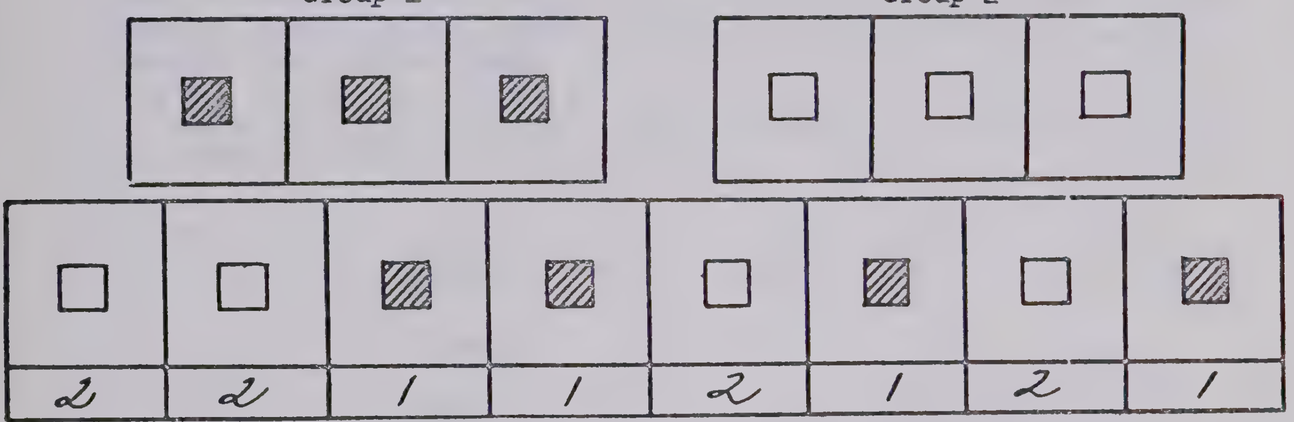
Name: ____

FIGURE CLASSIFICATION — I-3

This is a test of your ability to discover rules that explain things. In each problem on this test there are either two or three groups, each consisting of three figures. You are to look for something that is the same about the three figures in any one group and for things that make the groups different from one another.

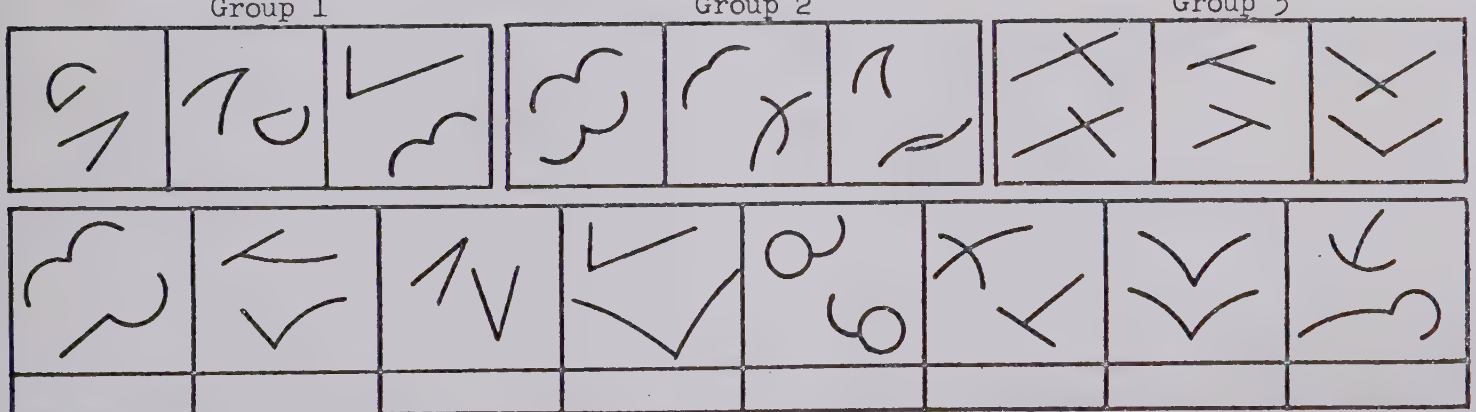
Now look at the sample problem below. In the first line, the figures are divided into Group 1 and Group 2. The squares in Group 1 are shaded and the squares in Group 2 are not shaded. In the second line a 1 has been written under each figure that has a shaded square as in Group 1. A 2 has been written under each figure with an unshaded square as in Group 2.

Group 1 Group 2



Now try this more difficult sample, which has three groups:

Group 1 Group 2 Group 3



The figures in Group 1 consist of both straight and curved lines. The figures in Group 2 consist of curved lines only. The figures in Group 3 consist of straight lines only. As you can see, there are other details that have nothing to do with the rule. The answers are: 1, 1, 3, 1, 2, 1, 2, 2.

Your score on this test will be the number of figures identified correctly minus a fraction of the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you have some idea of the group to which the figure belongs.

You will have 8 minutes for each of the two parts of this test. Each part has 4 pages. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Name: ____________________

OBJECT - NUMBER TEST — Ma-2

This is a test of your ability to learn combinations of words and numbers. In each part of the test you will study a page showing 15 object names with numbers. After studying the page showing both objects and numbers you will turn to a page showing the names of the objects in a different order. You will be asked to write down the numbers that go with them.

Here is a practice list. Study it until you are asked to turn to the practice test page (1 minute).

Object	Number
window	73
desk	41
carpet	19
door	84
glass	90

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Name: ____

FIRST AND LAST NAMES TEST — Ma-3

This is a test of your ability to learn first and last names. In each part of the test you will study a page of 15 full names, first and last. After studying the page showing full names you will turn to a page showing a list of the <u>last</u> names in a different order. You will be asked to write the <u>first</u> names that go with each last name.

Here are some practice names. Study them until you are asked to turn to the next page (1 minute).

Janet Gregory

Thomas Adams

Roland Donaldson

Patricia Fletcher

Betty Bronson

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Name: ______________________________

ADDITION TEST — N-1

This is a test to see how quickly and accurately you can add. It is not expected that you will finish all the problems in the time allowed.

You are to write your answers in the boxes below the problems. Several practice problems are given below with the first one correctly worked. Practice for speed on the others. This practice may help your score.

Practice Problems:

4	7	12	84	7	34	17	45	31	80
9	6	5	54	38	81	50	41	52	78
1	15	67	72	80	51	74	89	19	15
14									

Your score on this test will be the number of problems that are added correctly. Work as rapidly as you can without sacrificing accuracy.

You will have 2 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Name: ____

SUBTRACTION AND MULTIPLICATION TEST — N-3

This is a test to see how quickly and accurately you can subtract and multiply. It is not expected that you will finish all the problems in the time allowed.

You are to write your answers in the boxes below the problems. Several practice problems are given below with the first one correctly worked. Practice for speed on the others. This practice may help your score.

If you wish, you may use the space between the lines or at the bottom of the page for scratchwork.

Practice Problems:

Subtract:

98	40	37	84	81	76	59	90	46	56
-75	-35	-19	-47	-38	-40	-46	-31	-29	-23
23									

Multiply:

86	67	30	81	42	37	81	86	43	69
x 6	x 4	x 3	x 8	x 5	x 8	x 4	x 3	x 6	x 7
516									

Your score on this test will be the number of problems solved correctly. Work as rapidly as you can without sacrificing accuracy.

You will have 2 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Name: ______________________________

MATHEMATICS APTITUDE TEST — R-1

In this test you will be asked to solve some problems in mathematics. Solve each problem and put an X through the number in front of the answer that you select.

Example

How many pencils can you buy for 50 cents at the rate of 2 for 5 cents?

1-10
2-20
3-25
4-100
5-125

Your score on this test will be the number marked correctly minus a fraction of the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have 10 minutes for each of the two parts of this test. Each part has 3 pages. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Name: ____

NECESSARY ARITHMETIC OPERATIONS TEST — R-4

This test consists of problems in mathematics. However, instead of solving the problems and finding an answer, your task will be merely to indicate which arithmetic operations could be used, if you solved the problems. Put an X through the number in front of the option that you select.

Example I

If a man earns $2.75 an hour, how many hours should he work each day in order to make an average of $22.50 per day?

1-subtract
2-divide
3-add
4-multiply

In order to solve the problem you should divide $22.50 by $2.75; therefore, you should have put an X through 2.

Example II

Desks priced at $40 each are being sold in lots of 4 at 85% of the original price. How much would 4 desks cost?

1-divide and add
2-multiply and multiply
3-subtract and divide
4-multiply and divide

One way to solve the problem would be to multiply $40 by .85 and then multiply this product by 4; therefore, you should have put an X through number 2. (Although some problems may be solved in more than one way, as with Example II, only the operations for one of these ways will be given among the options).

When 2 operations are given, they are always given in the order in which they should be performed.

Your score on this test will be the number marked correctly minus a fraction of the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have 5 minutes for each of the 2 parts of this test. Each part has 3 pages. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Suggested by Necessary Operations by J. P. Guilford

Name: ____

VOCABULARY TEST — V-1

This is a test of your knowledge of word meanings. Lock at the sample below. One of the four numbered words has the same meaning or nearly the same meaning as the word at the left. Indicate your answer by writing, in the parentheses at the right, the number of the word that you select.

attempt 1-run 2-hate 3-try 4-stop . . . . . ( )

The answer to the item is number 3; you should have a "3" written in the parentheses.

Your score will be the number marked correctly minus a fraction of the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have 4 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Adapted from a test by J. B. Carroll

Name: ______________________________

VOCABULARY TEST — V-2

This is a test of your knowledge of word meanings. Look at the sample below. One of the five numbered words has the same meaning or nearly the same meaning as the word above the numbered words. Mark your answer by putting an X through the number in front of the word that you select.

jovial

1-refreshing
2-scare
3-thickset
4-wise
5-jolly

The answer to the sample item is number 5; therefore, an X has been put through number 5.

Your score will be the number marked correctly minus a fraction of the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have 4 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

APPENDIX B

DOCUMENTATION OF COMPUTER PROGRAM

FOR SIMULATION GAME

C O M P U T E R - A S S I S T E D - I N S T R U C T I O N

COURSE DOCUMENTATION

Course Title:	fishy
Educational Level:	Junior High School
Author:	J. Dale Burnett
Programmer:	J. Dale Burnett
Computer:	IBM 1500 System
Language:	Coursewriter II
Date:	December, 1970

Division of Educational Research
The University of Alberta
Edmonton, Canada

fishy

Information for Educator

1. Objectives and Purpose of Program

The primary reason for writing the program was to collect data on student performance on a simulation game for use in a Ph.D. thesis. However the simulation of the fishing industry was selected because of its' relevance to the Junior High School Social Studies curriculum on primary industries. It is expected that this program could be incorporated into an existing unit on primary industries.

2. Course Content

The program gives a brief description of the importance of the salmon fishing industry. This is followed by the actual simulation exercise. There are four distinct versions of the simulation game, referred to as Model 1, Model 2, Model 3, and Model 4. These models are described in section 6, Method of Instruction.

3. Educational Level

The content is suitable for Junior High School Social Studies curriculum. The program is suitable for all age levels over 12 years. Since the program contains 4 models of increasing complexity, younger students may find the larger models too difficult, however at present there is no data available to make an evaluation of this possibility.

4. Source of Course Content

None.

5. Program Duration

No data available at time of documentation. An estimate of one hour appears reasonable.

6. Method of Instruction

Simulation game

MODEL 1:

a) Objectives

i) the student should understand the relationship of market price and amount of fish caught to cash received

ii) the student should understand the relationship between number of fish caught and resultant fish population for the following year.

b) Form of equations

initialization

$$M_T = 10$$
$$V_T = 500$$
$$S_T = 100$$
$$F_T = 300$$

equations

$$S_T = S_{T-1} + R_1 \quad , -5 \le R_1 \le 5 \qquad (1)$$
$$M_T = M_{T-1} + R_2 \quad , -1 \le R_2 \le 1 \qquad (2)$$
$$F_T = S_T (F_{T-1} - C_T) /70 \qquad (3)$$
$$V_T = V_{T-1} + (C_T M_T /10) \qquad (4)$$

where S_T represents reproduction and survival factor

M_T represents the market price (a stochastic variable)
F_T represents number of fish at time T
C_T represents number of fish caught at time T
V_T represents value of cash on hand at time T
R_1, R_2 are random numbers

Therefore model 1 contains 2 random variates, 5 variables, and 4 equations. The student has direct control over 1 variable, C_T.

MODEL 2:

a) Objectives

i) objectives of model 1

ii) the student should understand that the number of employees affects the number of fish caught.

iii) the student should understand the relationship between value of equipment and both the cash on hand, and the number of fish caught.

iv) the student should understand the value of a balance between number of employees and value of machinery.

b) Form of equations

initialization

$M_T = 10$

$V_T = 500$

$S_T = 100$

$F_T = 300$

$E_T = 400$

$P_T = 150$

equations

$$S_T = S_{T-1} + R_1 \quad , -5 \le R_1 \le 5 \qquad (1)$$

$$M_T = M_{T-1} + R_2 \quad , -1 \le R_2 \le 1 \qquad (2)$$

$$E_T = E_{T-1} + N_T \qquad (3)$$

$$P_T = P_{T-1} + A_T \qquad (4)$$

$$C_T = f(E_T, P_T) \qquad (5)$$

$$F_T = S_T (F_{T-1} - C_T)/70 \qquad (6)$$

$$V_T = (V_{T-1} + (C_T M_T)/10) - A_T \qquad (7)$$

where E_T represents number of employees at time T

N_T represents number of new employees at time T (may be 0)

P_T represents value of fishery

A_T represents value of an addition or maintenance to plant or equipment

$f\ (E_T, P_T)$ is given in graphical form at the end of this section. The corresponding analytic description is as follows:

if $E_T < 60$, $C_T = 0$

if $P_T < 80$, $C_T = 0$

if $60 \leq E_T < 160$, then

a) if $80 \leq P_T < 240$, $C_T = \dfrac{P_T - 80}{50} \cdot \dfrac{F_T}{10}$

b) if $240 \leq P_T < 420$, $C_T = 3.2 + \dfrac{P_T - 240}{225} \cdot \dfrac{F_T}{10}$

$$= \frac{P_T + 480}{225} \cdot \frac{F_T}{10}$$

c) if $P_T \geq 420$, $C_T = 4.0 + \dfrac{P_T - 420}{450} \cdot \dfrac{F_T}{10}$

$$= \frac{P_T + 1380}{450} \cdot \frac{F_T}{10}$$

if $160 \leq E_T < 350$, then

a) if $80 \leq P_T < 240$, $C_T = \dfrac{P_T - 80}{40} \cdot \dfrac{F_T}{10}$

b) if $240 \leq P_T < 420$, $C_T = 4.0 + \dfrac{P_T - 240}{129} \cdot \dfrac{F_T}{10}$

$$= \frac{P_T + 276}{129} \cdot \frac{F_T}{10}$$

c) if $P_T \geq 420$, $C_T = 5.4 + \dfrac{P_T - 420}{400} \cdot \dfrac{F_T}{10}$

$$= \frac{P_T + 1741}{400} \cdot \frac{F_T}{10}$$

5

if $E_T \geq 350$, then

a) if $80 \leq P_T < 240$, $C_T = \frac{P_T - 80}{36} \cdot \frac{F_T}{10}$

b) if $240 \leq P_T < 420$, $C_T = 4.4 + \frac{P_T - 240}{100} \cdot \frac{F_T}{10}$

$$= \frac{P_T + 200}{100} \cdot \frac{F_T}{10}$$

c) if $P_T \geq 420$, $C_T = 6.2 + \frac{P_T - 420}{267} \cdot \frac{F_T}{10}$

Therefore model 2 contains 2 random variates, 9 variables, and 7 equations. The student has direct control over 2 variables, N_T and A_T.

MODEL 3:

a) Objectives

i) objectives of model 2.

ii) student should understand concept of depreciation and the need for maintenance of equipment.

iii) student should be aware of a natural turnover of staff.

iv) student should be aware that payment of salaries must be taken into consideration when determining number of employees.

v) student should be aware of demands for raises.

b) Form of equations

initialization

$M_T = 10$
$V_T = 500$
$S_T = 100$
$F_T = 300$

$E_T = 400$
$P_T = 150$

$H_T = 30$

equations

$$S_T = S_{T-1} + R_1 \qquad , -5 \le R_1 \le 5 \qquad (1)$$
$$M_T = M_{T-1} + R_2 \qquad , -1 \le R_2 \le 1 \qquad (2)$$
$$E_T = E_{T-1} + N_T - R_3 E_{T-1} \qquad 0 \le R_3 \le 0.09 \qquad (3)$$
$$P_T = P_{T-1} + A_T - 0.13 P_{T-1} \qquad (4)$$
$$C_T = f\,(E_T, P_T) \qquad (5)$$

$$\text{if } T = 3 \text{ or } 8 \;,\; H_T = 1.25\,H_{T-1} \qquad (6)$$
$$F_T = S_T\,(F_{T-1} - C_T)\,/\,70 \qquad (7)$$
$$V_T = V_{T-1} + (C_T\,M_T)\,/\,10 - A_T - H_T\,E_T\,/200 \qquad (8)$$

where R_3 is a random number representing rate of men leaving their job.

H_T represents the average salary at time T. Therefore model 3 contains 3 random variates, 10 variables, and 8 equations. The student has direct control over 2 variables, N_T and A_T.

MODEL 4:

a) Objectives

i) objectives of model 3

ii) student should understand that water pollution will have a detrimental effect on the survivial factor of the fish.

iii) student should realize the benefits that may result from construction of fish ladders.

b) Form of equations

initialization

$$M_T = 10$$
$$V_T = 500$$
$$S_T = 100$$
$$F_T = 300$$

7

$E_T = 400$

$P_T = 150$

$H_T = 30$

$L_T = 100$

$D_T = 150$

equations

$L_T = L_{T-1} + X_T$ (1)

$D_T = D_{T-1} + W_T$ (2)

$S_T = S_{T-1} + R_1 + 0.1\ (L_T/18 + D_T/21) \quad , -5 \le R_1 \le 5$ (3)

$M_T = M_{T-1} + R_2 \quad , -1 \le R_2 \le 1$ (4)

$E_T = E_{T-1} + N_T - R_3\ E_{T-1} \quad , 0 \le R_3 \le 0.09$ (5)

$P_T = P_{T-1} + A_T - 0.13\ P_{T-1}$ (6)

if $T = 3$ or 8 , $H_T = 1.25\ H_T$ (7)

$C_T = f\ (E_T, P_T)$ (8)

$F_T = S_T\ (F_{T-1} - C_T)/70$ (9)

$V_T = V_{T-1} + (C_T M_T)\ /\ 10 - A_T - H_T\ E_T/200 - X_T - W_T$ (10)

where L_T represents value of fish ladders at time T

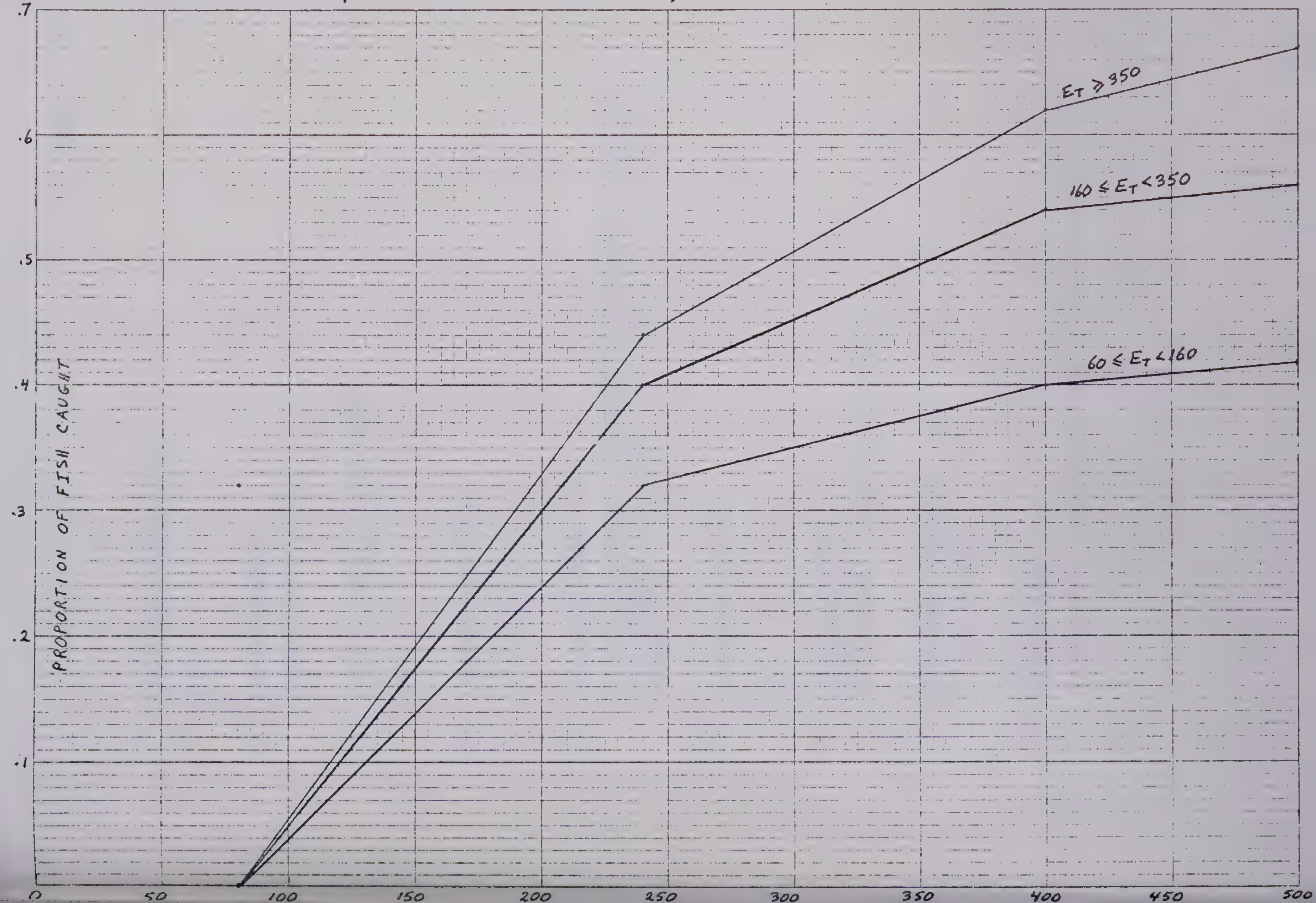
X_T represents amount spent on ladders at time T

D_T represents value of purification equipment at time T

W_T represents amount spent on purification at time T

Therefore model 4 contains 3 random variates, 14 variables, and 10 equations. The student has direct control over 4 variables, X_T, W_T, N_T, and A_T.

Functional Relationship Between C_T and (E_T, P_T)



7. Audio-Visual Requirements

   None.

8. Response Modes

   Keyboard and light-pen.

9. Student Operating Requirements

   None.

10. Teacher Supervision

    Not required.

11. Evaluative Information

    Standard performance recordings are maintained. No data has been analyzed at this time. This program will be used in the programmer's thesis.

12. Auxiliary Materials

    None.

13. Student Reaction

    Not available at time of documentation.

14. Programmer and Author

    J. Dale Burnett

15. Availability

    Unrestricted, but permission should be requested of author.

Information for Operator

1. Course Name and Segments

   fishy-000

2. Dictionaries and Graphic Sets

   Standard dictionary only.

3. Functions Called

   mv, ei, ra.

4. Macros Called

   dua007, tla007.

5. Film Reels

   None.

6. Audio Tapes

   None.

7. Execution Time

   Approximately 1 hour.

8. Response Time

   Response times are included with ep instructions.

9. Pre-Course Instruction Requirements

   The "student name" field at the time the student is registered must conta a one-digit integer (1, 2, 3, or 4) to indicate the simulation model. the student is to use. A 1 indicates Model 1 a 2 indicates Model 2, etc. A description of the models is given in the section, "Information for the Education, 6. Method of Instruction." The operator should ensure that this information is provided by the person requesting the program.

10. Student Sign-On Command

Standard sign-on.

11. Teacher Supervision

Not required.

12. Proctor Messages

Message: INCORRECT REGISTRATION
ENTER THE MODEL NUMBER (1, 2, 3, 4)
AT THE STUDENT STATION

Reason: The program extracts an integer from the "student name" field in buffer 0 after the student signs-on. The above proctor message will appear if a value of 1, 2, 3, or 4 is not encountered.

Action: The following message will appear at the student terminal-

PLEASE WAIT FOR THE PROCTOR TO COME TO YOUR TERMINAL.

The program will be at an ep instruction. The proctor must enter a one digit number (1, 2, 3 or 4) at the student termi This value corresponds to the model of the fishing industry that the student is to use. This information should have been supplied at the time the user requested the scheduling of the program. A further description of the four models is given in the section, "Information for the Educator, 6. Method of Instruction."

Message: Please help this student use the l-pen.

Reason: The student is required to point the light-pen at the 'target' after the word END. The student has timed out after 100 seconds.

Action: (1) Explain the use of the light-pen to the student.
(2) Have the student point to the 'target', the course will then continue.

Message: Help this student use the keyboard.

Reason: The student is required to type the number 1960. The student has either timed out after 2 minutes or a value other than 1960 has been entered.

Action: (1) Explain the use of the keyboard to the student. In particular explain the use of the integers on the top row of the keyboard (including the numbers 1 and 0).

(2) Explain how to enter a response.

(3) Have the student type the number 1960, the course will then continue.

13. Performance Recordings

Performance recordings will usually be made.

14. Special Instructions for Operator

See 9. Pre-Course Instruction Requirements and 12. Proctor Messages.

Information for Programmer

1. Course Listing and Flow-Chart

   360 output of Documentation is enclosed. 360 output of How-Charting program is enclosed.

2. Macros Called

   dua007 - press space bar to continue.
   tla007 - time out.

9. Special Programming Features

   The value of buffer 0 after the student signs-on is searched using function *ei* (Extract integer) and the numerical value is stored in counter 29. This value must be 1, 2, 3, or 4. The logic branches to the appropriate simulation model (1, 2, 3, or 4) depending on the value of counter 29.

   This procedure makes use of the fact that the value of the "student name" field at the time the student number is registered is stored in buffer 0 when the sign-on procedure is completed.

10. Programmers Name and Date of Documentation

    J. Dale Burnett.

DOCUMENTATION TABLE

Segment	Buffers	Counters & Cntr/Sw.	Switches	Ret. Reg.	Functions	Graphics	Dictionaries
0	B0, B1	C0 to C29 inclusive	2, 3, 4, 5, 6, 7, 8, 9.	1	mv, ei, ra.		

4. Counters Used

Since counters are used extensively in this course, the following table is provided to give the correspondence between the variables in the game models and the counters used in the program.

COUNTER	VARIABLE		INITIAL VALUE
C1		current 'year' for the game	1960
C2	M_T	market price	10
C3	C_T	number of fish caught	0
C4	V_T	value of cash on hand	500
C5	S_T	reproduction and survival factor	100
C6	F_T	number of fish in ocean	300
C7		dummy storage for intermediate results	
C8		"	
C9		profit for year	0
C10	E_T	number of employees	400
C11	P_T	value of fishery equipment	150
C12	N_T	number of new employees at time T	0
C13	A_T	value of addition or maintenance to plant or equipment at time T	0
C14	H_T	average salary	30
C15	L_T	value of fish ladders	100
C16	X_T	amount spent on fish ladders at time T	0
C17	D_T	value of anti-pollution measures	150
C18	W_T	amount spent on anti-pollution measures at time T	0
C19		stored value of V_T for year 1 , C1 = 1960	
C20		stored value of V_T for year 2 , C1 = 1961	
C21		stored value of V_T for year 3 , C1 = 1962	
C22		stored value of V_T for year 4 , C1 = 1963	
C23		stored value of V_T for year 5 , C1 = 1964	
C24		stored value of V_T for year 6 , C1 = 1965	
C25		stored value of V_T for year 7 , C1 = 1966	
C26		stored value of V_T for year 8 , C1 = 1967	
C27		stored value of V_T for year 9 , C1 = 1968	
C28		stored value of V_T for year 10 , C1 = 1969	
C29		average value of counters 19 to 28. (C29 also contains the model number at the time of sign-on).	

APPENDIX C

DOCUMENTATION OF COMPUTER PROGRAM

FOR MFF TEST

figur

C O M P U T E R - A S S I S T E D - I N S T R U C T I O N

COURSE DOCUMENTATION

Course Title:	Matching Familiar Figures
Grade:	Grades 1 - 12
Author:	J. Dale Burnett
Computer:	IBM 1500 System
Language:	Coursewriter II
Date:	October, 1970

Division of Educational Research Services

The University of Alberta

Edmonton, Canada

figur

Information for the Educator

1. Objectives and Purposes

The program provides a computer-based presentation of Jerome Kagan's Matching Familiar Figures (MFF) test. This test may be used to provide measures on an "Impulsivity - Reflectivity" scale. This version of the test requires a student to select a matching figure from among six choices.

2. Course Content

The test contains two practise trials:

Trial 1 : cups
Trial 2 : rulers

Following are twelve trials, presented in the order:

Trial 3 : houses
Trial 4 : scissors
Trial 5 : phones
Trial 6 : bears
Trial 7 : trees
Trial 8 : leaves
Trial 9 : cats
Trial 10 : dresses
Trial 11 : animals
Trial 12 : lamps
Trial 13 : boats
Trial 14 : cowboys

For each trial the student is shown a picture of one figure separated from a set of six figures by a solid line. The student is required to select the figure from the set of six that is identical to the single figure.

If a student selects an incorrect choice during the two practise trials a message is displayed giving the reason why he was wrong and he is branched back to the same problem and asked to try again. If he is correct he receives confirmation and is branched to the next problem in the sequence. The same pattern is repeated for the next twelve trials except if he is incorrect he is merely told to try again - no message is given explaining why he was wrong.

figur

3. Age and Educational Level

A non computer-based version of this test has been used for children in Grades 1 - 6. However, an upper limit has not been determined. It is desirable that the test represent a balance between not being too easy and not being too difficult. It is probable that this test would be satisfactory for children in grades 7 - 12 as well but this has not been validated. An adult version of the test exists that has eight choices instead of six for each item. The instructions may be given either visually on the CRT screen or verbally via earphones. If the instructions are presented on the CRT, it is obvious that the child must be able to read. A rough criteria might be to use the audio system for grades 1 - 6 and the visual system for grades 7 and over.

4. Source of Course Content

Kagan, J., Pearson, L., and Welch, L. Conceptual impulsivity and inductive reasoning. Child Development, 1966, 37, 583-94.

Gupta, P.K. Correlates of reflection-impulsivity. Ph.D. Thesis, 1970, Dept. of Educational Psychology, University of Alberta.

5. Program Duration

The program will take from 5 to 20 minutes depending on the student.

6. Method of Instruction

See number 2, Course Content, of this documentation.

7. Audio Visual Requirements

a. Film reel UA122 is required.
b. Special note on registration of students: If the instructions are to be given via the audio unit, the "student name" field must contain the integer "1". In this case audio tape AC-42 is required.

   If the instructions are to be presented on the CRT, no audio tapes are required. In this case the "student name" field must contain the integer "0". It is important that the operators are informed of the value to be given to the "student name" field, or the program will not execute properly.

8. Response Modes

The student uses the light pen to indicate his choice for each item.

figur

9. Student Operating Requirements

None.

10. Teacher Supervision

Not required.

11. Evaluative Information

Standard performance recordings are maintained. The following data is stored for each record:

Student identifier
Date
Response identifier
Match identifier
Latency.

No data has been analyzed at this time. This program will be used in the programmer's thesis.

12. Auxiliary Materials

None.

13. Student Action

Not available at time of documentation.

14. Programmer and Author

J. Dale Burnett.

15. Availability

Restricted distribution, communicate with author.

Information for the Operator

1. Course Name and Segments

   Course Name: *figur* Segment 000.

2. Dictionaries and Graphic Sets

   Standard Dictionary only.

3. Functions Called

   ei

4. Macros Called

   dua007, *tla007*.

5. Film Reels

   Film Reel: UA122, Frames 241-254 Inclusive.

6. Audio Tapes

   Optional - see 14. Special Instructions.
   If used, audio tape AC-42 is required.

7. Execution Time

   5 - 20 minutes.

8. Response Times

   Response times are included with *ep* instructions.

 figur

9. Pre-Course Instruction Requirements

None.

10. Student Sign-On Command

Standard Sign-on procedure. There are no code words.

11. Teacher Supervision

No required

12. Proctor Messages

None.

13. Performance Recordings

A performance pack or tape is required. The following data should be stored for each record:

Student identifier
Date
Response identifier
Match identifier
Latency.

14. Special Instructions

Important note on registration of students. The "student name" field must contain either the integer "0" or the integer "1". An "0" indicates no audio tapes are used.
An "1" indicates that audio tape AC-42 must be used.

Information for the Programmer

1. Course Listings and Flow-Chart

See documentation package in DERS library.
The student is given two practise trials (picture of cups and picture of rulers) where he is required to choose the matching figure from among six choices. If he is wrong a message is given explaining the reason why he was wrong and he is branched back to the same problem and asked to try again. If he is correct he received the next problem in the sequence. The same pattern is repeated for the next twelve trials except if he is incorrect he is merely told to try again - no message is given explaining why he was wrong. Summarizing, the program consists of a linear sequence of fourteen trials where the student must correctly answer the present trial before going on to the next trial.

2. Macros Called

Macro	*dua007*	- press space bar to continue
	tla007	- time out

See The University of Alberta 1500 Instructional System - Macro Guide for a complete description of these two macros.

3. Buffers Used

After the student signs-on, buffer 0 will contain the "student name" field that is specified at the time of registration. This field must contain either an "0" or an "1".

Buffer 0 will also contain the student's response to an *ep* instruction. This is a standard feature of the 1500 system.

4. Counters Used

C1 - contains the value of the integer extracted from buffer 0 at the time of sign-on.
0- no audio
1- use audio

 figur

5. Switches Used

S1 - set equal to 1 if a value of 1 is extracted from buffer 0 at the time of sign-on.

6. Return Registers Used

None.

7. Functions Called

ei

8. Graphic Sets and Dictionaries

None.

9. Special Programming Features

The value of buffer 0 after the student signs-on is searched using function *ei* (extract integer) and the numerical value is stored in counter 1. This value must be either 0 or 1. If the resulting counter 1 is equal to 1, the logic branches to that portion of the program that uses audio for all instructions, otherwise no audio is used.

This procedure makes use of the fact that the value of the "student name" field at the time the student number is registered is stored in buffer 0 when the sign-on procedure is completed.

10. Programmers Name

J. Dale Burnett

Symbolic Name	Q-Tone	Message
Group Mark # 1	GM	
FI1	BOM	Matching Familiar Figures
	EMP	You will be shown a picture of something you know and beside it will be some pictures that look like it. There will be a line between the picture that is by itself and the others. You will have to choose the picture that is just like the picture which is by itself. Now look at the screen above the keyboard. Use the light pen to point to the square on the screen that is in the same place as the picture you choose. Let's do some for practise.
	EOM	
CU1	BOM	Please point to the square that is in the same place as the picture you choose.
	EOM	
CU2	BOM	Please answer as quickly as possible.
	EOM	
CU3	BOM	Very good. That was the correct choice.
	EOM	
CU4	BOM	No. You pointed to the square on the left in the top row. This means you chose the cup with the dots on it. The picture by itself has lines on it. You must choose the cup that is the same as the one which is by itself. Please try again.
	EOM	

Symbolic Name	Q-Tone	Message
CU5	BOM	No. You pointed to the middle square in the top row. This means you chose the plain cup with the square handle. The picture by itself has lines on it. You must choose the cup that is the same as the one which is by itself. Please try again.
	EOM	
CU6	BOM	No. You pointed to the square on the right in the top row. This means you chose the striped cup with no handle. The picture by itself has a handle. You must choose the cup that is the same as the one which is by itself. Please try again.
	EOM	
CU7	BOM	No. You pointed to the middle square in the bottom row. This means you chose the cup with the triangles on it. The picture by itself has lines on it. You must choose the cup that is the same as the one which is by itself. Please try again.
	EOM	
CU8	BOM	No. You pointed to the square on the right in the bottom row. This means you chose the blank cup with the curved handle. The picture by itself has lines on it. You must choose the cup that is the same as the one which is by itself. Please try again.
	EOM	
CU9	BOM	You must point to one of the six squares on the screen. Please try again.

Symbolic Name	Q-Tone	Message
	EOM	
Group Mark # 2	GM	
RU1	BOM	Please point to the square that is in the same place as the picture you choose.
	EOM	
RU2	BOM	Please answer as quickly as possible.
	EOM	
RU3	BOM	Very good. That was the correct choice. Now we are going to do some that are a little bit harder. Find the picture that is just like the one that is by itself.
	EOM	
RU4	BOM	No. You pointed to the square on the left in the top row. This means you chose the short ruler with marks on it. The ruler by itself is a longer ruler. Choose the ruler that is the same as the one which is by itself. Please try again.
	EOM	
RU5	BOM	No. You pointed to the middle square in the top row. This means you chose the shorter ruler with no marks on it. The ruler by itself is a longer ruler. Choose the ruler that is the same as the one which is by itself. Please try again.
	EOM	
RU6	BOM	No. You pointed to the square on the right in the top row. This means you chose the short ruler with no marks on it. The ruler by itself is a

Symbolic Name	Q-Tone	Message
		longer ruler. Choose the ruler that is the same as the one which is by itself. Please try again.
	EOM	
RU7	BOM	No. You pointed to the square on the left in the bottom row. This means you chose a shorter ruler. The ruler by itself is a longer ruler. Choose the ruler that is the same as the one which is by itself. Please try again.
	EOM	
RU8	BOM	No. you pointed to the middle square in the bottom row. This means you chose a shorter ruler with marks on it. The ruler by itself is a longer ruler. Choose the ruler that is the same as the one which is by itself. Please try again.
	EOM	
RU9	BOM	You must point to one of the six squares on the screen. Please try again.
	EOM	
GE1	BOM	Please point to the square that is in the same place as the picture you choose.
	EOM	
GE2	BOM	Please answer as quickly as possible.
	EOM	
GE3	BOM	Very good. That was the correct choice.
	EOM	
GE4	BOM	No. Pick the picture that is the same as the picture by itself. Please try again.

Symbolic Name	Q-Tone	Message
	EOM	
GE5	BOM	You must point to one of the six squares on the screen. Please try again.
	EOM	
Group Mark # 3		

APPENDIX D

HANDOUT ON

STUDENT USE OF THE COMPUTER TERMINALS

STUDENT USE OF THE COMPUTER TERMINALS

Notice that each terminal contains

1. a cathode-ray display screen (like a small TV screen)

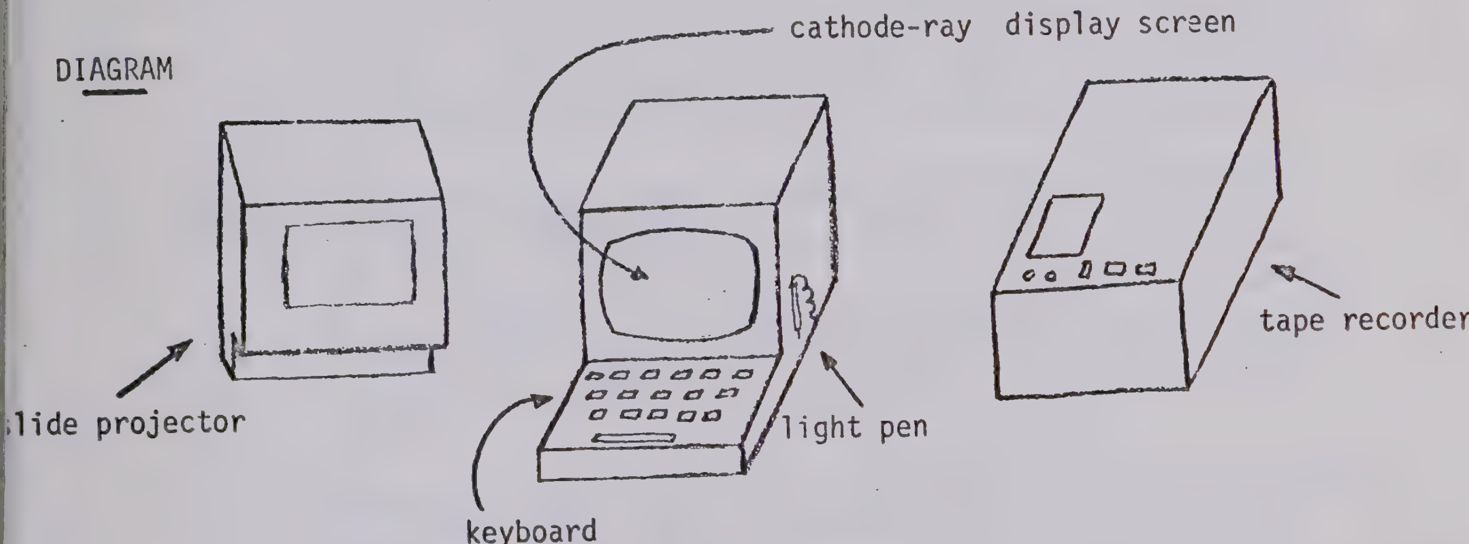
2. a keyboard (like a typewriter)

3. a light pen (located on the right-hand side of the display screen)

4. An slide projector (this is the large 'box' located to left of the display screen)

5. a tape recorder (this is the large 'box' located to the right of the display screen).

DIAGRAM



All of the instructions are shown on the cathode-ray display screen. Some of the courses may ask you to use either the light pen or the keyboard, or both. However you do not have to worry about what you are supposed to do, since instruction will always be given on the display screen explaining what is wanted.

A course may use the slide projector to show you some pictures or the tape recorder to play a message, but most courses only use the display screen, light-pen, and the keyboard.

Using the keyboard

Most courses will ask you to type an answer to a question that appears on the display screen. Thus it is important that you know how to use the keyboard.

Step 1 Whenever the computer wants you to type an answer, the letter K (the letter K means keyboard response) will appear in the bottom right corner of the display screen.

Never type in an answer unless there is a K in the bottom right corner of the display screen.

Always type in an answer when there is a K in the bottom right corner of the screen.

Step 2 Press the keys on the keyboard to give your answer. Usually your answer will appear on the display screen. If you make a mistake before you are finished hold the "altn coding" button on the top left corner down and then press the backspace button (on the top right corner of the keyboard) until your answer is erased from the display screen. Then retype your answer.

Step 3 This is the final step. You must let the computer know that you have finished your answer. This is done by "entering" your answer. To enter an answer first press the "altn coding" button on the top left corner down and then press the space bar. Be sure to hold the "altn coding" button down while you press the space bar. After you have entered your answer, the letter K will disappear from the bottom right corner of the display screen.

Remember, if you have finished typing your answer and the letter K is still in the bottom right corner of the display screen, you must "enter" your answer.

Using the light pen

Remember that the light pen is found on the right-hand side of the display screen.

Many of the courses will ask you to indicate your answer by pointing your light-pen at a particular point (usually called a 'target') on the display screen.

Step 1 Whenever the computer wants you to use the light pen, the letter P (the letter P means light-pen response) will appear in the bottom right corner of the display screen.

Step 2 Point the light pen at the 'target' (this is usually a square) and press it (firmly, but not too hard) against the screen. As soon as the computer recognizes what you have pointed to, the letter P will disappear from the bottom right corner of the display screen.

REMEMBER

1. The course will contain complete instructions on what is required.

2. The letter K in the bottom right corner of the display screen means that you are to type an answer.

3. The letter P in the bottom right corner of the display screen means that you are to use the light pen.

4. If there is no K or P in the bottom right corner, you are not expected to give an answer. Be sure to wait for the K or P to appear before answering a question.

5. If you are not sure of what you are supposed to do, please raise your hand and the computer operator will help you.

The first time you use the terminals everything is new and appears strange, but it is much like learning how to use a new tool - once you have used it a few times, you become familiar with the way it works and it becomes much easier to use.

APPENDIX E

FORM REQUESTING PARENT'S PERMISSION

January 5, 1971

To the Parents of ______________________ ;

Your student has been selected by a random procedure for participation in a study to be conducted at the University of Alberta.

This study will provide further data on two relatively new developments in Education - that of computer assisted instruction and that of simulation gaming. Each student will be transported to the Education building on the University of Alberta campus where he/she will participate in a simulation game based on the salmon fishing industry in British Columbia. This will take approximately one hour. All of the selected students will also receive a set of tests which will be given at Wellington Junior High School following the simulation game. There should be a minimum of disruption from the normal school schedule. All results will be kept completely anonymous and confidential - only results of the group as a whole will be reported.

The study has the endorsement of the Edmonton Public School Board, and the principal of Wellington Junior High School, Mr. J. Marles.

It would be appreciated if this form could be signed and returned as soon as possible.

APPENDIX F

RAW SCORES ON MARKER TESTS FOR COGNITIVE FACTORS

APPENDIX F

RAW SCORES ON MARKER TESTS FOR COGNITIVE FACTORS

Subject ID	I-1	I-3	Ma-2	Ma-3	N-1	N-3	R-1	R-4	V-1	V-2	MFF-1	MFF-2
1	18	44	6	8	47	59	12	10	12	8	2	265
2	22	138	9	14	31	41	21	18	20	12	2	445
3	11	48	10	11	30	41	6	11	12	4	2	320
4	13	55	9	10	18	21	6	12	6	7	6	222
5	22	94	15	15	20	36	6	13	10	3	0	548
6	13	59	7	6	24	30	4	9	12	13	2	668
7	0	79	4	16	23	39	7	8	8	8	5	85
8	14	70	15	20	22	40	3	9	11	3	16	201
9	18	39	11	17	21	22	3	11	20	9	0	546
10	11	71	13	14	37	63	3	7	15	13	3	241
11	13	40	4	9	20	39	8	7	2	8	14	272
12	3	50	3	8	29	40	0	5	6	10	17	196
13	15	55	9	13	38	50	4	9	11	8	1	534
14	23	110	19	19	47	67	11	13	23	13	0	421
16	15	53	3	6	38	58	0	5	3	1	5	134
17	23	119	13	17	58	85	22	22	18	13	5	605
18	20	61	12	16	29	32	4	9	8	14	2	328
19	21	72	17	15	42	54	11	7	11	10	1	327
20	14	62	20	20	33	32	4	9	12	5	11	138
21	20	47	4	8	27	40	5	10	10	11	0	252
24	22	45	12	19	33	38	11	8	12	5	1	297
25	12	69	5	5	8	21	6	12	15	18	0	583
26	16	49	11	20	23	33	4	10	19	10	11	126
27	9	36	7	12	25	26	5	12	4	5	2	352
28	14	43	24	21	34	49	10	11	14	7	1	438
31	14	70	20	13	37	56	4	12	8	9	3	355
32	22	71	25	18	31	33	8	10	11	8	1	617
33	19	61	26	16	39	46	6	15	10	12	15	274
34	11	46	9	20	23	30	7	9	15	7	1	329
35	13	0	30	30	35	45	7	17	26	19	1	557
36	23	63	6	9	41	52	4	10	2	8	4	319
37	16	61	8	13	32	42	7	10	13	5	0	528
38	17	26	15	15	37	55	5	12	9	19	7	334
39	16	102	12	21	29	34	9	12	22	18	3	571
40	15	77	10	13	24	48	9	15	4	5	1	111

APPENDIX F (Continued)

Subject ID	I-1	I-3	Ma-2	Ma-3	N-1	N-3	R-1	R-4	V-1	V-2	MFF-1	MFF-2
41	0	55	29	17	28	43	5	9	2	9	5	290
42	22	131	10	14	33	47	8	14	18	15	1	231
43	1	68	20	11	23	23	8	13	8	4	13	192
45	15	84	10	16	23	32	1	6	14	8	6	181
46	18	67	5	4	39	55	5	15	14	13	1	230
47	26	73	23	18	30	36	14	20	23	20	3	178
48	5	46	4	7	18	19	3	8	4	2	10	331
49	20	34	25	14	38	53	5	11	7	4	5	223
51	20	90	16	19	25	39	8	12	10	7	1	472
52	22	76	23	19	30	33	8	10	15	8	3	335
53	23	62	17	25	27	32	7	16	28	23	0	434
54	7	91	9	11	32	43	5	10	6	9	4	274
55	26	49	8	14	30	55	11	13	11	7	1	612
56	21	89	24	28	36	45	18	13	9	11	0	781
57	19	117	12	22	42	52	11	11	15	11	1	350
58	18	64	16	26	43	57	8	13	8	3	8	215
59	16	68	3	9	42	48	7	12	15	9	3	212
60	21	53	20	23	52	59	9	16	32	30	0	416
61	14	58	7	11	22	28	7	10	10	9	7	259
62	17	40	10	15	30	37	13	13	20	19	1	601
63	21	30	27	20	60	74	8	15	12	5	11	262
64	19	37	12	14	22	21	1	9	18	6	10	209
65	17	66	11	19	35	44	5	9	8	9	0	303
66	14	74	13	25	42	38	10	9	10	8	0	643
67	19	71	29	13	42	63	6	8	14	2	5	182
68	14	72	21	18	45	55	10	12	12	3	14	313
69	7	53	23	22	29	35	9	12	16	11	6	189
70	16	65	11	18	28	31	1	10	10	9	2	250
72	11	83	8	14	31	36	7	13	17	16	4	413
73	19	97	13	21	28	53	6	11	26	16	2	272
74	21	120	7	11	29	28	13	15	19	15	2	408
75	21	68	17	16	38	63	9	16	8	10	0	708

N = 67

Note: MFF-1: Number of errors on MFF test

MFF-2: Average latency time per figure on MFF test (tenths of seconds)